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Unscrambling the Dielectric Constant

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FOR a century or more the dielectric constant has appeared in most of our lecture rooms on the first day of the course in electricity in the familiar equation,

$$F = qQ/\epsilon r^2. \qquad (1)$$

In this equation it has been used for comparing the force between two charged bodies immersed in oil with the force they would have in air or vacuum. At the same time, however, it has also been assigned a rôle analogous to that of the constant of Newton's law of gravitation; and in this rôle it has helped us to define the electrostatic system of units. Later it has reappeared on the stage, when condensers were needed in alternating current theory. And finally it has helped to enact the climax of the course by taking on unfamiliar dimensions when it appeared in Maxwell's equations.

It has seemed capable of playing all these parts because for so many years a material medium was supposed to differ from vacuum only in that the ether in the medium was weakened in such a way as to require less force for a given electric displacement. The displacement vector D might indeed be split into two parts, E and $4\pi P$, but the distinction between these two parts was for many years not particularly sharp. Now, however, with our present knowledge of electrons and of the nature of dielectric polarization, a question arises whether we are not asking too much of the dielectric constant. Specifically, are we not asking it to measure at the same time two quantities of very different nature—one connected with E and the other with P? And do we want to give any quantity in our equations such a dual personality?

When we consider the polarization of a dielectric to be a matter of displacement of electrons, and consider a vacuum to have no electrons to be displaced, is the force exerted by Q on q when they are in oil quite so simple as we had once thought? Is it like the force between these charges in vacuum, a single phenomenon, or is it a composite of electrostatic and molecular forces? Suppose, for example, we think of the charges as placed on two metal balls immersed in oil and then consider what happens in the molecules of the oil. The oil is polarized, of course, either by displacement of electrons within the molecules, or by orientation of molecules inherently polar. At any given point in the oil, well away from the metal balls, we are just as likely to find the positive end of a molecule as the negative, and there is no resultant charge density. Where the oil touches the metal, however, we find a surface charge. Assuming q to be positive and assuming that the ball was given this charge q before it was immersed in the oil, we may think of the metal as holding this charge q, while the oil molecules in contact with it present their negative ends to it, thus giving the surface of the oil around that ball a charge $-q'$. To get away from all implications of the term dielectric constant, let us follow a suggestion of Birge[1] and talk in terms of the specific inductive capacity κ, defined as the ratio of the capacitance of a given condenser in oil to

[1] R. T. Birge, Am. Phys. Teacher **2**, 1 (1934).

its capacitance in vacuum. With this definition and the assumption that the oil does not "weaken the ether" it is easy to show[2] that

$$q' = q(1 - 1/\kappa). \tag{2}$$

Using electrostatic units one might be tempted to predict that the electrostatic force between the balls could be calculated as

$$F = (Q - Q')(q - q')/r^2, \tag{3}$$

where Q' is defined like q'. This, however, turns out to be not the force in vacuum divided by κ, but by κ^2.

Looking for a reason for this discrepancy, the question arises, just what mechanical system is it, for which we are finding the resultant force? Is it simply the metal ball with its free charge q, or does it include also the negative ends of the molecules around the ball which constitute the polarization charge $-q'$? Assuming the latter alternative, the resultant force is not simply the electrostatic force exerted on the net charge $(q-q')$, because every negative end of a molecule in the charge $-q'$ is really in equilibrium between the electrostatic force due to all other charges and the intramolecular force (electrostatic or otherwise) that holds it within the molecule. This intramolecular force is therefore equivalent to the electrostatic force that would act on a charge $+q'$ situated as $-q'$ is. If q and $-q'$ are not coincident in space, but form an unbalanced double layer, there may be forces, both electrostatic and molecular, between them; but such forces are internal to the system whose resultant force we are finding. So the force on $+q'$, to which the external molecular forces on $-q'$ are equivalent, is the electrostatic force that only Q and $-Q'$ would exert. We have, therefore, for the whole system

$$F(\text{electrostatic}) = (Q - Q')(q - q')/r^2,$$
$$F(\text{molecular}) = (Q - Q')(+q')/r^2;$$

adding these,

$$F(\text{resultant}) = \frac{(Q - Q')q}{r^2} = \frac{Qq}{\kappa r^2}, \text{ Q.E.D.} \tag{4}$$

The conclusion from this is that the experiment of hanging two charged balls in oil is not so simple as it looks, because the intramolecular forces acting on the polarization charges of the oil are essential parts of the mechanism, whereas in vacuum we have only the purely electrostatic action-at-a-distance. On the other hand, when the intramolecular forces are cancelled off against the action-at-a-distance on $-q'$ it is found that the force actually exerted on the system as a whole is given by the same equation that would hold if q and the net charge $(Q-Q')$ were in vacuum. That is, it is evident that the old hypothesis of a "weakening of the ether" within the oil does not have to be invoked, and must indeed be explicitly denied, for an explanation of the observed force consistent with modern knowledge.

With these facts in mind, we can now distinguish sharply between the two effects to be measured. One is the ability of the oil to produce polarization charges. The other is the ability of any charges such as q and $(Q-Q')$, to exert electrostatic forces upon one another. These purely electrostatic forces depend only on the magnitudes of the charges and the distance between them, and not on whether either charge happens to be a resultant of free and polarization charges. Thus it is evident that the constant in the equation for purely electrostatic forces is just as invariable as the constant of gravitation.

Why not, then, separate these two phenomena in our teaching, and treat them one at a time? First, considering electrostatic charges in vacuum, let us set up the law for them by analogy with the already familiar law of gravitation. For example, we can use parallel columns,[3] thus:

Gravitation	*Electrostatics*
$F = kMm/r^2$	$F = jQq/r^2$
M and m are masses; force, always an attraction; $k = 6.673 \times 10^{-8} \frac{\text{dyne cm}^2}{\text{gram}^2}$.	Q and q are charges; force, repulsion if positive; $j = 8.9873 \times 10^{+18} \frac{\text{dyne cm}^2}{(\text{int. cou.})^2}$.

In the gravitation equation, the gram, the dyne and the centimeter have already been defined in ways independent of that law. In the electrostatic equation, we may or may not have defined the coulomb previously; but in any case, the international coulomb, since it depends on electrolysis, is defined without reference to

[2] See, for example, L. Page and N. I. Adams, Jr., *Principles of Electricity*, Chapter II; for an especially rigorous mathematical treatment see, M. Mason and W. Weaver, *The Electromagnetic Field*, Chapter I.

[3] D. L. Webster, H. W. Farwell and E. R. Drew, *General Physics for Colleges*, Rev. ed., p. 412.

electrostatics, and can therefore be used in that equation without dependence on the equation itself. On the other hand, we can of course define the statcoulomb, as to its magnitude, by so choosing it as to make

$$j=1\frac{\text{dyne cm}^2}{\text{statcoulomb}^2}, \text{ exactly;} \qquad (5)$$

and we may define its dimensions arbitrarily to cancel the units of j completely. This constant, j, being analogous to the constant of gravitation, might well be called the *constant of electrostatics*. We can then use this law with either unit as we please, and develop as much of the theory of electrostatics in vacuum as we wish, before the dielectric constant or specific inductive capacity needs to be mentioned.

When we do come to dielectrics, the most important problem in practice is of course that of the capacitance of a condenser, and the specific inductive capacity is defined very readily in terms of this problem. The problem of forces on charges immersed in oil is of course interesting from a theoretical standpoint, and perhaps for its application to electrostatic voltmeters. But its theoretical interest is by no means what it had been supposed to be in the old days when the oil was supposed to "weaken the ether." In fact, the question arises whether the force between charges in oil might not as well be relegated to a completely secondary place, in an advanced course, and left off the front page entirely.

With regard to the dielectric constant, which has heretofore staggered under the combined tasks of both the constant of electrostatics j, and the specific inductive capacity κ, we can of course define it as $\epsilon=\kappa/j$. This gives ϵ as heretofore its variability from one substance to another in proportion to κ. Likewise, it gives ϵ the dimensions of $1/j$; and whatever statements may be made about the dimensions of ϵ can be made equally well about this factor, leaving κ free of all dimensions.

For the theory of the distribution of electrostatic fields in dielectrics of finite volume, we can still use the dielectric displacement D as heretofore, and the question arises whether to define D as ϵE or κE. Either definition is workable, the former giving to Poisson's equation the form

$$\text{div } D=4\pi\rho, \qquad (6)$$

and the latter the form

$$\text{div } D=4\pi j\rho. \qquad (6')$$

Which form to use is perhaps a question of convenience. We are accustomed to writing

$$D=E+4\pi P, \qquad (7)$$

which would imply that D, E and P are all of the same dimensions. By defining D as κE, we preserve the dimensional identity of D and E. But for P, defining it as usual, as dipole moment per unit volume, we must write

$$D=E+4\pi jP. \qquad (7')$$

On the other hand, defining D as ϵE, we have

$$D=E/j+4\pi P. \qquad (7'')$$

To avoid unnecessary fractions, the former alternative, $D=\kappa E$, is more convenient. In either case, of course, whenever we use the electrostatic system of units, thereby making $j=1$ and cancelling its units, j disappears.

For Maxwell's equations, where ϵ again figures prominently in current discussions, there are again great advantages in splitting its properties between j and κ. The identity of the velocity of electric waves in vacuum with that of light is then carried, along with the dimensional properties, by the constant of electrostatics j, in conjunction with a similar constant for the magnetic interaction of electric currents. Meanwhile, the dimensionless but variable feature of wave velocities, namely the refractive index, is carried by the dimensionless but variable quantity κ.

Altogether, this method of treatment shortens the hours of labor for the dielectric constant ϵ as a single quantity practically to zero, by giving it only the rôle of a convenient abbreviation for κ/j. As such, of course, it is occasionally useful, though not essential.

Finally, let me add a word as to experience with this method of handling electrostatics in the classroom. The separation of the two diverse tasks of the dielectric constant accomplishes exactly what one might expect, by enabling us to treat them one at a time and keep them simple and clear.

The Philosophical Problem of the Existence of the Physical World

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THE fundamental assumption of physical science is that there exists a physical world of which we have some knowledge. The contemporary physicist has evidence that his world consists of electrons, protons, radiation, and so forth. The philosophical problem which I propose to consider in this paper is the status of the physical world in the system of reality. That there is a problem to be investigated is indicated by the fact that the philosophy of Ernst Mach[1] implies that the physical world as I have just characterized it is a fiction. In contemporary discussion H. Dingle[2] has argued that microscopic entities such as electrons are purely conceptual and P. W. Bridgman[3] has set forth the view that light as "something that travels" is a fiction. These examples reveal the significance of the question, what is the meaning of the existence of the physical world?

A physicist who undertakes to examine philosophical answers to our problem is undoubtedly bewildered and indeed repelled by the anarchy which prevails in this field. Theories range from *idealism*, according to which mind is the primary reality, to *materialism* in which mind is merely a character of natural events; from *monism*, according to which there is one kind of reality, to *pluralism* in which there are many kinds of reality; from *rationalism*, which expresses the assumption that knowledge is derived from reason, to *empiricism* which is grounded in experience, more specifically, sensation. In the present discussion of the physical world I shall introduce the philosophical issues gradually. Accordingly I shall distinguish three levels of analysis, those of (1) theory of scientific method (2) theory of knowledge and (3) speculative metaphysics.

Although the natural scientist is disposed to criticize philosophers for their failure to achieve a common doctrine, vigorous attempts to escape from the strife of metaphysical systems have been made by the philosophers themselves. In contemporary philosophy there is an active group which repudiates traditional metaphysics and endeavors to introduce scientific method in philosophy, to use an expression of Bertrand Russell. The movement to purge philosophy of speculative metaphysics has its roots in the British empiricism of the eighteenth century. It was initiated by Locke, but Hume made the most thorough attempt to restrict the concern of the human understanding to that which can be known through experience. In the first half of the nineteenth century August Comte founded *positivism*, according to which theology and metaphysics are stages in a development which culminates in the positive scientific description of phenomena. The empirical method became an influence in theoretical physics through the work of Mach. In the latter part of the nineteenth century he taught that reality consists of the things which are given in sensation. Things consist of complexes of pressures, colors, sounds, etc., which he characterizes as elements in order to express neutrality with respect to traditional metaphysical theories. The function of science is the economical description of correlations of elements given in sensation. In recent years the development of mathematical logic, especially the theory of classes and relations, has furnished tools for the carrying out of the project which was envisioned by Mach. Thus Russell[4] developed a theory in which physical things are constructed out of their perspectives. A more recent and detailed theory is that of Carnap,[5] whose work is the most notable product of the movement which is called *logical positivism*. Its most distinguished leaders are L. Wittgenstein[6] of Cambridge, M. Schlick[7] of Vienna, and R. Carnap and Philipp Frank[8] of Prague. H.

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[1] E. Mach, "The Economical Nature of Physical Enquiry," *Popular Science Lectures*, Open Court, 1895.
[2] H. Dingle, *Science and Human Experience*, Macmillan, 1932.
[3] P. W. Bridgman, *The Logic of Modern Physics*, Macmillan, 1927.
[4] B. Russell, *Our Knowledge of the External World*, 2nd edition, Norton, 1929.
[5] R. Carnap, *Der Logische Aufbau der Welt*, Weltkreis-Verlag, 1928.
[6] L. Wittgenstein, *Tractatus Logico-Philosophicus*, Kegan Paul, 1922.
[7] M. Schlick, *Positivismus und Realismus*, Erkenntnis, **3**, 1 (1932).
[8] P. Frank, *Das Kausalgesetz*, Springer, 1932.

Reichenbach[9] is accounted a member of the movement, although he recognizes as significant, problems which the others would hold to be meaningless. In the United States logical positivism is represented by H. Feigl and A. Blumberg.[10] An allied point of view is expressed by the *conceptual pragmatism* of C. I. Lewis.[11] The present writer[12] has developed the fundamental concepts of the physical world by a positivistic method as a basis for a critical development of the system of physical theory. With this introduction we proceed to the theory of scientific method, which is an analysis of concepts in a manner which avoids traditional metaphysical issues.

Theory of Scientific Method

The theory of scientific method is an analysis of the concepts through which we describe, interpret and explain the things given in experience; it is a characterization of the objects which we assume as the ground of experience of the world. I shall analyze our concepts by sketching the steps by which one may build a concept of the physical world. Now obviously, the starting point for physics must be experience, more precisely, the data of sensation. But as we shall see, it is necessary to assume physical reality beyond sense-data in accordance with definite principles. Accordingly I make this preliminary methodological note. Principles which appear to be derived from experience serve as definitions through which we introduce the concepts of new objects. In particular, the principle of contiguous causality serves as a definition.

The fundamental fact of experience is that we perceive physical things. Thus at the present moment I am seeing and touching a desk. Analysis reveals that an essential characteristic of perception is that an object is given in sensation, a sense-datum. If we abstract from the circumstance that the object is given we shall call it an *aspect* or *perspective* of the thing which is perceived. In perception we interpret a given aspect as that of some thing. Thus I specifically characterize perception as the interpretation of sensations as experiences of things. Perception expresses a judgment and may be true or false.

We are now ready for a definition of a *thing*. On the present perceptual level of analysis a thing is something of which it is possible to experience aspects in sensation. A thing is something that presents aspects to a mind (which may be interpreted as a nervous system). I distinguish between *given* and *possible* aspects of a thing. Thus at the present moment the desk which I am perceiving has aspects which are the objects of possible sensation from different points of view. If I should walk around the desk I could experience visual aspects of it which at the present moment are possible aspects. Thus on this level of analysis, that a thing exists when not perceived implies that it is possible to experience aspects of the thing. A thing is something whose aspects are possibilities of sensation. The empiricist John Stuart Mill described matter as the permanent possibility of sensation.

On the perceptual level our empirical definition of a thing is that it is a class of aspects. The properties of a thing are defined in terms of the characters of the aspects. For example, the position of a thing is defined in terms of its tactual aspects: a thing is where it is determined to be by touch. Now visual aspects are found to be correlated with tactual aspects, hence a visual aspect may be interpreted as that of a thing. Thus from a given visual aspect we can infer the character of a correlated possible tactual aspect. By convention we locate the visual aspect at the position of the correlated tactual aspect. On the preceding basis we can begin to build physical science; thus we may define space, time, motion and formulate laws of motion. In particular, from the interaction of things in collisions we should be led to formulate a principle of contiguous causality, the principle that physical action occurs between things in contact.

The development of physics, however, requires the introduction of *constructive* concepts; it is necessary to pass from a perceptual level to a constructive one. This transition may be exemplified by the definition of radiation. Let us then suppose that I can touch a thing, but can-

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[9] H. Reichenbach, "Ziele und Wege der physikalischen Erkenntnis," *Handbuch der Physik*, ed. by Geiger and Scheel, IV, 1929.

[10] H. Feigl and A. Blumberg, "Logical Positivism," J. Phil., **28**, 281 (1931).

[11] C. I. Lewis, *Mind and the World Order*, Scribner's, 1929.

[12] V. F. Lenzen, *The Nature of Physical Theory*, John Wiley and Sons, 1931.

not see it. Under appropriate conditions the thing becomes visible; that is, it becomes possible to experience visual aspects which are correlated with the tactual aspects of the thing. For example, if I introduce a lighted candle into a dark room things become visible; I may experience visual aspects of a table. The thing, therefore, has been influenced by the candle. Now if we restrict ourselves to what is perceptible we must think of this influence as an action at a distance. The physicist, however, interprets the process as an action by contiguous causality. Accordingly, we define radiation through the principle that the visual aspect of a thing, as defined in terms of touch, is functionally related to radiation which travels from a source to the thing. The principle of contiguous causality in this instance constitutes a definition of radiation. If I keep the illuminated thing constant, as estimated by tactual aspects, and change the source of radiation, the visual aspect changes, in color, for example. If I keep the source constant and vary the thing illuminated, the visual aspect changes. Hence we must think of the visual aspect as functionally dependent upon the radiation and thing conjointly. The visual aspect manifests the reaction of the thing to radiation. In uncritical terms, the visual aspect is produced by the scattering of radiation by the thing. The preceding statement expresses a principle which may be viewed as a generalization from experience, based upon the definition of a thing in terms of tactual aspects and the definition of radiation through visual aspects and the principle of contiguous causality. In the development of physics, however, the principle that a thing scatters radiation becomes a definition of physical reality. Thus if we look through a microscope and see a visual pattern we interpret it as the aspect of a thing which may transcend touch. Our definition of physical reality is the principle that physical reality scatters radiation and thereby produces visual aspects. Radiation produces aspects which we directly apprehend; it also produces new things like spectral lines on photographic plates, which in turn become visible when illuminated. Electrons are assumed to scatter radiation which, however, is not able to produce individual visual aspects. Since we have adopted a new definition of physical reality we are able to apply the theory of production of aspects to touch.

We have seen that a visual aspect is the joint product of the radiation and the thing. In uncritical terms, the visual aspect may be thought of as the effect of a thing. Now recalling Roemer's observations on the moons of Jupiter we assume that the state of the thing to which a visual aspect belongs is prior to the apprehension of the aspect as a datum of sensation. Accordingly, strictly speaking sight and touch allow us to infer the existence of a perceived thing only at a time earlier than the perception, by means, for example, of the principle that radiation is scattered by a thing. We assume the existence of a thing prior to the time of the state which produces the datum on the basis of the principle of contiguous causality; that is, physical reality is assumed to have existed in the past in the sense that from this assumption we can deduce by principles which exemplify contiguous causality the characters of the physical world which are revealed in perception at the present time.

I shall not discuss the introduction of other constructive concepts, those of molecules, atoms, electrons, protons, etc. The constitutive character of the fundamental entities of the physical world is that they scatter and emit or absorb radiation. The definitions of these entities, however, require principles such as those of conservation, which exemplify the principle of contiguous causality in interactions between the microscopic entities and large-scale things.

We started out on the perceptual level with the definition that a thing is a class of given and possible aspects and defined its physical properties in terms of tactual aspects. In consequence of our analysis we now conceive of a thing as something that scatters radiation and thereby produces visual aspects or other effects. Tactual aspects are then to be explained as are visual aspects. One should add that the nervous system cooperates in the production of sense-data. Thus we must distinguish between the physical thing and the datum of sensation. To the thing are assigned properties which differ somewhat from those directly determined from the data of perception. In particular, the state of the thing perceived is prior to the time of its perception. Now since we interpret the data of sensation as

the effects of interactions between physical objects we deprive the physical world of its intuitive qualities. Hence the thing as well as radiation becomes the object of conceptual thought. Thus the physical world becomes a schema which extends as a framework throughout the realm of sensory experience. The most general relational characters of the schema are expressed by the concepts of space and time. The positions and dates of possible aspects are defined in terms of the space-time characters of the physical things which are assumed as the origins of the aspects.

Thus we may distinguish *perceptual*, *constructive* and *schematic* levels in the theory of scientific method. The final result of physical theory is that the physical world is a structural schema which is the object of a hypothetico-deductive system which serves to interpret and predict the data of sensation of a normal organism. The physical world exists in the sense that it is possible to assume a set of physical objects such as electrons, radiation, etc., which are assumed to satisfy certain laws, and deduce the occurrence of physical processes to which are correlated specific objects of sensation or perception. Thus an electromagnetic wave is a physical process to which is correlated the color of a visual aspect, or the position of a spectral line on a photographic plate. Briefly, but uncritically, the physical world exists in the sense that it may be assumed as the cause of the data of perception.

Theory of Knowledge

In the preceding section we considered functional relations between objects such as visual aspects, radiation and physical things, without raising the problem of their ultimate status in reality. The analysis was restricted to the level of scientific method. It appears, however, that it is possible to ask questions such as the following. What is the status of an aspect while it is merely possible? Is a given aspect created or discovered in the process of sensation? What is the nature of the relation between physical objects such as electromagnetic waves and the colors manifested by sense-data? The foregoing questions belong to that field of philosophy called *theory of knowledge* or *epistemology*.

Now. at the very outset one is confronted by a difference of opinion as to the significance of the foregoing problems. The logical positivists, for example Carnap and Schlick, declare that the epistemological problem is an illusory one. The question, is the object of sensation discovered or created in the process, is held to be not significant. Indeed, most of the major historical philosophical issues are declared to have been meaningless. According to logical positivism the function of philosophy is the clarification of meaning. Philosophy does not consist of a set of propositions which express knowledge of reality. Science is the only form of knowledge and the function of philosophy is to analyze the meaning of scientific concepts in the manner exemplified in the preceding section. The fundamental assumption of logical positivism is that the meaning of any assertion is exhibited in the method of testing its truth or falsity; if an assertion can neither be proved nor disproved it is meaningless. Now the fundamental epistemological issues cannot be decided by experience and hence such problems are *Scheinprobleme*.

Now although logical positivism is an attempt to introduce scientific method into philosophy, there are philosophers, equally devoted to science, who recognize the significance of the problems of theory of knowledge. I may mention Bertrand Russell and C. D. Broad.[13] Broad, for example, emphatically rejects speculative philosphy, but asserts the value of critical philosophy which raises the fundamental issues of theory of knowledge. In any event, I shall assume the significance of the problems and shall sketch the principal solutions.

The central problem is the status of aspects. Is a given aspect discovered or created in sensation? The naïve view is that aspects exist independently of being given; sensation is merely the discovery of a pre-existing entity. On the perceptual level a thing consists of all its independent aspects. This view, which may be called *naïve realism*, has been advanced in contemporary philosophy under the name *neo-realism*.[14] A fundamental objection to naïve realism is that it assumes a very complicated real world; all

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[13] C. D. Broad, *Scientific Thought*, Harcourt Brace, 1923.

[14] R. B. Perry, *Present Philosophical Tendencies*, Longmans, Green, 1912; E. B. Holt, *The Concept of Consciousness*, Macmillan, 1914; A. O. Lovejoy, *The Revolt against Dualism*, Norton, 1930.

possible aspects from all possible points of view are assumed to have independent existence.

The strongest argument against naïve realism is offered by the following considerations. Suppose that we have given a rod, a plane mirror and a source of light so arranged that one sees the rod in the mirror. The visual aspect that we see, the image of the rod, appears to be behind the mirror and by convention it is located as far behind the mirror as the rod is in front of it. If we accept the view that the visual aspect of the rod has independent existence then the mirror and radiation would be instruments of discovery. But if one employs this interpretation one would have to interpret physical conditions as instruments of discovery of pre-existing objects. Thus if a body is accelerated by a force the latter is merely an instrument which enables one to discover a pre-existing acceleration of the body. But this conclusion disagrees with the meaning of the empirical concept of production. Hence we must think of the mirror image and all aspects as produced by their conditions. It accords with our scientific ideas to call aspects *events*.

Having accepted the characterization of aspects as events our next problem is to consider whether aspects are to be thought of as constituents or as separated effects of a thing. Instead of the mirror-image let us consider the visual aspect of a distant twinkling star. The twinkling consists of variations in the visual aspect which are caused by fluctuations in the density of the atmosphere. Accordingly, if we assume that the visual aspect is a constituent of the distant star we must interpret the causal action of the atmosphere as an action at a distance. Indeed, since the aspect exists prior to our perception of it, the atmosphere which exists in the present must be thought of as producing an effect in the past. Now I assume that we wish to retain the principle of contiguous causality; therefore we must view the visual aspect, not as a constituent of the distant star, but as a separated effect which occurs at the end of a causal process. The position at the star which we assign to the visual aspect is merely apparent.

We have thus arrived at a definite distinction between the physical world and its aspects. There are two modes of interpreting the distinction, *classical dualism* and *phenomenalism*. The dualistic theory was stated by the ancient Greek philosopher Democritus. He said, "Sweet and bitter, cold and warm as well as the colors, all these things exist only in opinion and not in reality; what really exists are unchangeable particles, atoms, and their motions in empty space."[15] During the creative seventeenth century dualism was made the basis of philosophy of nature by Galileo, Descartes and Locke. Thus Locke distinguished between primary and secondary qualities. "Secondary qualities are nothing in the objects themselves, but powers to produce various sensations in us by their primary qualities, i.e., by the bulk, figure, texture and motion of their insensible parts, as colors, sounds, tastes, etc." The fundamental assumption of dualism[16] in modern terms is that the physical world of electrons, atoms, molecules and radiation is truly real, and that experienced aspects of things are events which are produced by the interaction of the physical world and nervous systems. Thus the image in the mirror is not really where it appears to be in physical space; the image is the final term of a series of physical processes which satisfy the principle of contiguous causality. The image immediately arises from the process in the brain. Since the pattern of the image is assumed to exhibit the pattern of the physical thing it follows that we can read off the structure of the thing from the image. Dualism appears to be required by a realism which is based upon a principle of contiguous causality. Causality is not merely functional relationship, as in the theory of scientific method, but efficient productivity.

The proponents of dualism feel that the positivistic concept of existence is too hypothetical and abstract; hence they categorically assume a concrete independent physical reality. The phenomenalists, on the other hand, limit themselves by the method of pure empiricism. According to phenomenalism sense-data are alone truly real; the physical world of electrons and radiation is a fiction. The principle of contiguous causality

[15] Quoted by H. Weyl, *Mind and Nature*, Univ. of Penn., 1934.

[16] Dualism has been defended in contemporary thought by: B. Russell, *The Analysis of Matter*, Harcourt Brace, 1927; C. D. Broad, *Scientific Thought;* M. Planck, *Where is Science Going*, Norton, 1932; A. Eddington, *The Nature of the Physical World*, Macmillan, 1929; A. O. Lovejoy, *The Revolt against Dualism*, Norton, 1930.

thus characterizes the fictitious world. As I have previously indicated, phenomenalism was set forth by Ernst Mach; in thus contrasting reality and fiction he went beyond the theory of scientific method.

Since the beginning of the twentieth century a new point of view, *pragmatism*, has gained wide acceptance. The basic assumption is that knowledge is practical in import, ideas are plans of action. In the *instrumentalism* of John Dewey the concept of the physical world is an instrument for the prediction and control of our experience. Thus by directing attention to the instrumental function of knowledge the pragmatist evades the problems created by the traditional concepts. It appears to the writer, however, that pragmatists tend to lapse into historical solutions. Thus William James frankly adopted naïve realism as a basis for his pragmatism. On the other hand, the humanist F. C. S. Schiller interprets knowing as a making of reality. A recent exposition of instrumentalism by C. W. Morris,[17] whose account has the approval of Dewey, adopts a generative theory of sense-data and has been analyzed by A. O. Lovejoy as dualism. Insofar as pragmatists express the empirically verifiable doctrine that the concept of the physical world is an instrument for the prediction of the data of sensory experience the point of view agrees with logical positivism. The predictive function of concepts is especially emphasized by C. I. Lewis, who characterizes a thing in terms of the correlation of experiences. Although the term experience has a phenomenalistic flavor, the intent is to express a neutral theory like the theory of scientific method of the preceding section.

Speculative Metaphysics

The choice of a particular theory of knowledge sets problems for a general theory of the nature of reality. Hence for those of a speculative turn of mind there is a third level of philosophical analysis, *speculative metaphysics*. In sketching some of these speculative theories I wish to emphasize that they are principally of historical interest. In view of the critical and scientific temper of the age, which is especially expressed by the interest in logical positivism, metaphysics is neglected by philosophers, although there are courageous exceptions such as Whitehead[18] and Boodin.[19] A metaphysical system is not to be understood as a rival of science, but an interpretation of the significance of nature in the total system of reality.

In the preceding section we saw that dualism has been an outstanding theory in the history of philosophy. The most interesting metaphysical theories have been attempts to interpret and transcend dualism. As I have pointed out, dualism was introduced into modern thought by Galileo and Descartes. In dualism the physical world is an independent reality and the data of sensation are events. Now Descartes characterized the data of sensation as mental and thereby interpreted epistemological dualism by a metaphysical dualism of matter and mind. Thus Cartesian dualism is the doctrine that reality consists of two interacting substances, matter, whose essence is extension, and mind, whose essence is thought. A large part of modern philosophy consists of attempts to overcome Cartesian dualism. Thus Spinoza proposed a *monistic* view: there is one substance, God, of whom extension and thought are infinite attributes. Physical things are modes of extension and ideas are modes of thought; there is a parallelism between the order of things and the order of ideas. Leibniz proposed a *spiritual pluralism*. The essence of matter is not extension, but the power of resistance and therefore force; accordingly Leibniz taught that reality consists of *monads* which are spiritual centers of force. The distinction between matter and mind is one of the degree of consciousness of the monads; thus material bodies consist of monads that are asleep. Every monad mirrors the universe and the monads are coordinated through a pre-established harmony. Descartes, Spinoza and Leibniz are called *rationalists* because they sought philosophical truth by reasoning from rational principles.

The rationalistic movement on the continent aroused a critical empiricistic reaction in Great Britain. Locke attacked the rationalistic method

[17] C. W. Morris, *Six Theories of Mind*, Univ. of Chicago, 1932.

[18] A. N. Whitehead, *Process and Reality*, Macmillan, 1929.

[19] J. E. Boodin, *Cosmic Evolution*, Macmillan, 1925.

of Descartes and sought to analyze the powers and limitations of the human understanding. He did, however, accept the dualistic assumption. This was criticized by Berkeley, who denied the existence of unthinking matter and asserted that "to be" is to be perceived by a mind. The Scottish philosopher Hume pursued the empirical method to its logical conclusion and landed in scepticism.

A fresh start was made by Kant. In an analysis of the structure of knowledge he recognized the function of fundamental concepts as instruments for the interpretation of experience. Empirical objects are constituted by the application of the forms of the mind to the material given in sensation. Thus the principle of causality, for example, is an instrument for the interpretation of experience, rather than an induction from experience. Kant reaffirmed dualism, however, in that he assumed things-in-themselves as the ground of the material of experience.

The followers of Kant sought to cast out the thing-in-itself as unknowable and therefore meaningless. Accordingly, the development of Kant's method led to highly speculative systems of *idealism*.[20] The upshot of this development was that reality is the experience of an absolute mind. But since the absolute experience transcends the experience of the human mind it follows that these idealisms recognize the dualism of theory of knowledge. That nature is the absolute spirit in self-alienation, as Hegel taught, does not conceal the fact that it is necessary to recognize a dualism between mind and nature.

As a concluding remark I would add that if physicists find the preceding speculations fantastic they will be in accord with the logical positivists who would declare that the problems and theories of the last two sections of this paper are meaningless.

[20] J. Royce, *Lectures on Modern Idealism*, ed. by J. Loewenberg, Yale Univ., 1919.

A Second Year Course in General Physics for College Transfer Students at the Massachusetts Institute of Technology

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PROBABLY no one would question the statement that college students who transfer from one institution to another prior to completing their undergraduate courses, give rise to problems in curriculum administration which are not always satisfactorily solved. Admissions officials cannot settle all the questions which arise in attempting to fit transfer students into already established programs by mere references to catalogs; courses in different schools are never exactly equivalent, and in some places curriculum experiments are being tried which make it practically impossible to evaluate transferred credits.

In many places, to be sure, this problem is relatively unimportant. But at the Massachusetts Institute this is not the case; in 1933, 132 undergraduate students were admitted by transfer. The reason behind these transfers seems to be in most cases a postponed ambition to acquire the sort of training offered in the several highly specialized technical courses at the Institute. In some cases it was found that the transfer was anticipated and deliberately arranged beforehand by the parents to follow a temporary sojourn elsewhere. Obviously then, the Institute officials are justified in giving special consideration to the problem of caring for these students, and it is the object of this paper to describe the manner in which the physics requirement is met when these transfers take place. The plan to be described represents an experiment in the teaching of elementary physics that has brought to light some interesting points.

The elementary physics requirement at the Institute is a two-year comprehensive course subdivided into four terms. The freshman year is devoted to the study of mechanics and heat,

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and the sophomore year, to electricity, optics and modern physics. Throughout all this work analytical methods are greatly stressed, and free use is made of the calculus. It might also be worth pointing out that during the last few years, because of the growing conviction that engineers of the future will require more training in fundamental physics than in the past, the scope of the work in this elementary course has been greatly extended.

Since most of the transfer students come from institutions where the physics requirement is limited to a one-year course, frequently a qualitative one, they do not fit readily into the foregoing program. This is not wholly because of the briefer course which they had, but also because of a conspicuous lack of ability to apply mathematics to physics. It must not be inferred that the colleges are to be criticized for presenting such qualitative courses; on the contrary, such courses are quite proper in "cultural" programs. Nor does it follow that there is any necessary lack of scholastic ability among these transfers; the contrary view is more often than not correct, for students who have a definite purpose in coming to the Institute are usually earnest and not infrequently very capable. For these reasons then it does not seem proper to refuse credit altogether for the previous work in physics, although it is obviously not a simple question of giving credit for the first year of work and requiring the student to take the second-year course.

To meet this situation, a special one-year course was planned by the writer and has been in use for several years. It is designed to supplement an average one-year course so that students who have shown distinction in an institution of recognized standing where physics is a one-year requirement, or who seem to be insufficiently prepared even though they may have had more physics than this, can hope to fulfill the Institute requirement by an additional year of work. It is distinctly a supplementary course and not the regular two-year course crowded into one year of work.

Experience has shown that the plans for such a course must be kept very flexible because of the heterogeneous nature of the student group; in 1933, for example, the 60 students admitted to the course represented more than 50 colleges in this country and abroad. On the other hand, the problem of determining the content of the hypothetical "average" course which the present course supplements is not so difficult as it may at first seem; it requires a familiarity with the various elementary textbooks and information obtained from interviews with many transfer students, supplemented by the findings of a so-called classification examination given at the beginning of the term.

During the course an attempt is made to review hastily the elementary concepts in a given branch of the subject and to follow this up with more rigorous considerations of advanced points. Throughout the course considerable emphasis is laid upon the unity of physics. This necessitates a logical and analytical development of the whole subject from fundamental assumptions, such as Newton's laws of motion, and it is often difficult to tie the material in with a student's preconceived notions. Here appears to be the crux of our whole problem: the one outstanding general characteristic which these men display in addition to an inability to apply mathematics to physics, is a lack of perspective in physics and orientation of point of view, which it might well be supposed that a preliminary survey course should give them.

The course is conducted on an informal-lecture basis, with problem discussions at frequent but irregular intervals. Problems, averaging four or five to each of the four lessons per week, are assigned for outside work, most of them being comprehensive and distinctly quantitative in character. The textbooks used in the regular courses are prescribed and the students are encouraged to refer often to other textbooks, particularly to the ones that they have already used. There is no laboratory work and few demonstrations, it being supposed that these portions of the work have already been stressed. At approximately two-week intervals one of the class hours is set aside for the working of problems by the students in class at their own seats. Here individual work is required, but free use of books and lecture notes is permitted. For this work credit is given on a relative or point basis. This procedure gives the instructor information concerning an individual student's progress with

respect to his fellow students. Hour examinations are also given at more or less regular intervals, and a three-hour comprehensive examination is given at the end of each term.

A prime requisite for the success of this experiment is a careful investigation of a prospective student's credentials by some one, preferably the instructor, to determine eligibility for the course. One must be always on the lookout for misfits, especially early in the term. The prospect of saving a year on the physics requirement is a strong temptation for a student to overrate his background and ability when applying for admission. In dealing with questionable cases it is often found advantageous, as well as diplomatic, to permit registration on condition and let the students find out for themselves what is required of them; many of them will drop out of their own accord after two or three weeks and enter the regular freshman course with the conviction that after all physics must not be slighted in preparation for an engineering career. In judging students who are slow in getting started one must be careful to distinguish between those who are insufficiently prepared and those who are temporarily handicapped by the change of environment incident to the transfer to another institution.

To add to the heterogeneity of the student group, it is found that the course attracts a number of graduate students who are majoring in fields other than physics and whose undergraduate preparation in physics does not meet the requirements of the Graduate School. These students do not as a rule like to comply with all the routine requirements of the course. They are often conspicuous for their poor preparation, although their maturity frequently contributes something to offset this difficulty. It might be added here that this course is distinctly not open to students who have already failed any portion of the regular course, even though some have advanced the belief that such a course would provide an excellent and suitable review.

On the whole, it is concluded that the plan here described is perfectly practicable. It does require, however, the development of a highly cooperative attitude between the class and the instructor, and the latter must be ready and willing at all times to adjust the course to fit unexpected circumstances. This, however, is no more than should be expected. As far as the students are concerned the opportunities offered by the course are appreciated and this appreciation is shown by a willingness to work hard. Of course the plan has not yet reached perfection but the difficulties are being overcome quite readily.

That the experiment has been successful thus far seems to be unquestioned. In February, 1933, for example, 81 percent of the class passed and 16 percent received the honor grade. Certain men of high scholastic ability who took the course have made the honors group at the Institute although it is certain that the lack of analytical training in physics which they displayed upon arrival was a real handicap to them. The success of the course justifies the claim that it is not necessary for all transfer students to take the entire two-year elementary course. Most of these students are serious and for such students there is really something to be said for a survey course followed by a supplementary analytical one. Such a repetition not only stresses in the student's mind the relative significance of the various branches of the subject but there is definite indication that those who have begun with the survey course exhibit a more enthusiastic appreciation for certain aspects of the mathematical developments than some of the regular students. As a rule they seem to acquire a sense of satisfaction in learning that their mathematics is worth something to them and in learning this while the mathematics is still fresh in their minds.

In conclusion I should like to emphasize the fact that the Society for the Promotion of Engineering Education has repeatedly recommended the teaching of more physics in engineering schools and that one possible way of accomplishing this goal in an institution where a more or less qualitative but well established one-year course is now the rule is to introduce a supplementary analytical course. This would have the advantage of giving the student a much broader knowledge of the whole field than the plan so common in many colleges of following up the elementary course with specialized semester courses in restricted fields. Of course, a number of schools do require a two-year elementary course but experience with many transfer students who have had such courses convinces one that even these institutions should consider the advantages of a second year course of the type here described.

OBVIOUS is the most dangerous word in mathematics.—E. T. BELL, *The Queen of the Sciences.*

Teaching Kirchhoff's Laws

L. E. WOODMAN, *Department of Physics, Missouri School of Mines and Metallurgy*

SEVERAL excellent college textbooks of general physics make no mention of Kirchhoff's laws, some mention them briefly in fine print, and a few give adequate treatment of these two fundamental laws of electrical circuits. Practically none of the books contain satisfactory problems. Either the problems can be solved more quickly by repeated applications of Ohm's law or else they become tedious and uninteresting because of the awkward numbers involved in the equations. One excellent teacher has made the statement that he could not take time enough from the teaching of physics to worry through the tiresome solution of simultaneous equations involved in solving problems using Kirchhoff's laws. Some teach the statement of the laws but do not properly bring out their meaning by applying them to actual circuits. The writer has for many years taught Kirchhoff's laws in the course in general physics for engineering students and has found that it takes three, or better four, days to train the average run of sophomores to solve problems which may be expressed in terms of three, and sometimes four, unknowns. The problems ordinarily used have been so constructed that the answers will be small whole numbers, thus reducing the amount of time spent on purely arithmetical processes to a minimum; this has the effect upon the student of making him feel that all problems must end in the same simple numbers and that his answers are surely wrong if they do not "come out even."

With these ideas in mind, the writer wishes to submit six problems for discussion and criticism, with the perhaps too bold assertion that they teach Kirchhoff's laws in a pleasing manner and without the objectionable solution of simultaneous equations. After a suitable foundation has been laid, the entire group can be discussed with the class in one lecture period. Throughout the discussion the emphasis can be put upon the physical principles involved, and such arithmetic as is necessary can be done in the head. Such problems are easy to devise; in fact the students themselves like to make them and try to see who can most cleverly conceal some important bit of information.

These problems involve a power of analysis which is very pleasing to certain students, but just as displeasing to others. Whether this power of analysis is a natural gift or whether it can be acquired seems to be uncertain, but if it can be cultivated no type of problem is better adapted for the purpose. Possibly this alone would justify spending a day or two on problems of this type. The average student is strong on substitution problems, where all he is expected to do is to substitute some numbers in a given formula. But here, alas! there is no formula, or at least the formula is not obvious until the situation has been sized up, and then the arithmetic is so simple that it seems but a minor part of the task. For this reason the average student does not like this type of problems for home work, especially if he is asked to submit written solutions, or for quizzes. This may be the best reason why he should be encouraged to work them mentally at first and then to put the complete solution on paper.

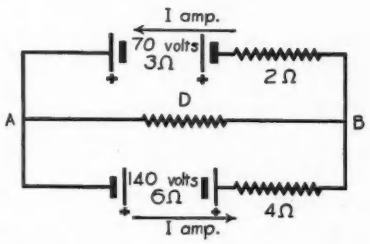

FIG. 1. Find the current and drop in potential in *ADB*.

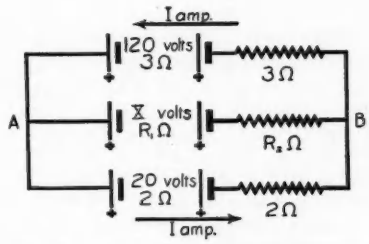

FIG. 2. In the middle branch, find I, X, R_1 and R_2.

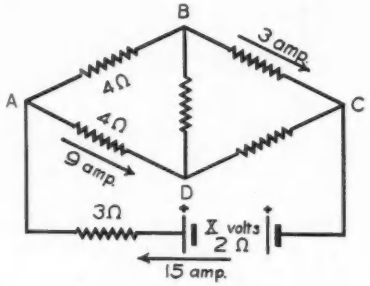

FIG. 3. Given $V_A - V_C = 60$ volts. Find the current, drop in potential and resistance in each branch.

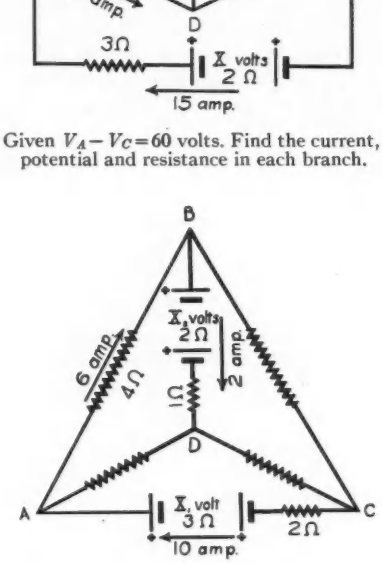

FIG. 4. Given: $V_A - V_C = 120$ volts, $V_A - V_D = 60$ volts. Find the current, drop in potential in each branch and the unknown resistances.

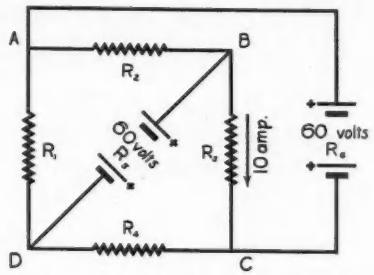

FIG. 5. Given: $V_A - V_B = V_C - V_D = 0$, $R_1 = R_2 = R_3 = R_4 = R_5 = R_6$. Find the current, drop in potential and resistance in each branch.

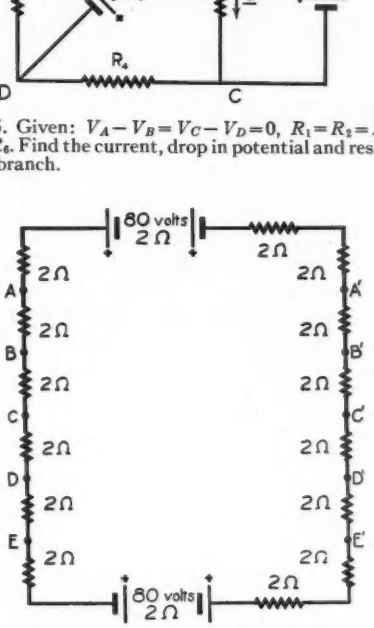

FIG. 6. Find the differences in potentials between the pairs of points AA', BB', $\cdots$, EE', CA' and CE'.

THE PROBLEMS

The analysis of the problem pictured in Fig. 1 might be written out as follows. Consider the branch point A. According to Kirchhoff's first law just as much current must leave that branch point as comes to it. A current of I amp. comes to this point and I amp. leave it. Hence the current in the branch ADB is zero and, consequently, the drop in potential between A and B is also zero. According to Kirchhoff's second law the drop in potential between A and B is the same no matter which path we take in going from A to B. In the upper path, it is equal to the e.m.f. of the battery minus the IR drop in that part of the circuit; or, $V_A - V_B = 70 - 5I = 0$. Similarly, for the lower path, $140 - 10I = 0$. Since there is no current in ADB, the IR drop is independent of the value of the resistance in this circuit; in other words, the resistance of ADB may be anything between zero and infinity.

The analysis of the problem pictured in Fig. 2 will not be given; it is enough like the one just analyzed so that it could be assigned for the student to work out by himself. Obviously the current in the middle branch between A and B must be zero, which means that a battery of $X = 60$ volts must be placed in this branch with the positive pole toward the left. It may take a little thought to decide whether to add the IR drop in the lower branch to the e.m.f. of the battery or to subtract it.

Fig. 3 looks like a Wheatstone's bridge. But is it a balanced bridge? Consider first the circuit containing the battery. Here $V_A - V_C = 60 = X - 5 \times 15$, or $X = 135$ volts, large enough to provide for an IR drop of 75 volts and still leave 60 volts as the drop in potential through any continuous path between A and C. Let us find the currents in the bridge proper: the current in AB is $15 - 9$ or 6 amp.; the current in BD is $6 - 3$ or 3 amp. (The bridge is not balanced); the current in DC is $9 + 3 = 12$ amp. It may be well to check the currents at the branch point C: it is $12 + 3 = 15$ amp., as it should be in accordance with Kirchhoff's first law. Now we can quickly find the IR drops in the various branches: $V_A - V_D = 9 \times 4 = 36$ volts; $V_D - V_C = 60 - 36 = 24$ volts; $V_A - V_B = 6 \times 4 = 24$ volts; $V_B - V_C = 60 - 24 = 36$ volts; $V_B - V_D = 36 - 24 = 12$ volts. The resistances are: $BC = 36/3 = 12$ ohms; $BD = 12/3 = 4$ ohms; $DC = 24/12 = 2$ ohms.

The problem pictured in Fig. 4 should untangle very readily, so its analysis is not given here.

In Fig. 5, $V_A - V_B = V_C - V_D = 0$. This reduces the problem to one of a series circuit containing an e.m.f. of 120

volts and a total resistance of $R_1+R_3+R_5+R_6$ ohms. The current is given as 10 amp. Hence: $R_1+R_3+R_5+R_6=12$ ohms; $R_1=R_2=R_5=R_6=3$ ohms; $V_A-V_D=10\times3=30$ volts; $V_D-V_B=60-10\times3=30$ volts; $V_B-V_C=10\times3=30$ volts; $V_C-V_A=60-10\times3=30$ volts.

In Fig. 6, what auxiliary circuit could be placed between A and A' and not disturb the flow of current in the given circuit? The current is obviously $160/32=5$ amp. This makes the drop in potential between A and A' equal to 40 volts; hence an e.m.f. of 40 volts and any resistance whatsoever could be placed between A and A' with the positive pole of the battery toward A. What could you place between B and B' and not disturb the flow of current in the given circuit? In the same way it would take an e.m.f. of 20 volts, with the positive pole toward B, and any resistance. Between C and C' the drop in potential is zero; hence a wire of any resistance or cells with zero e.m.f. can be placed between C and C' without affecting the current in the given circuit. Between D and D' it would take an e.m.f. of 20 volts with the positive pole toward D', and between E and E', an e.m.f. of 40 volts with the positive pole toward E'. Would it be possible to use all five of these auxiliary circuits at the same time? It can be quickly shown that such a combination would satisfy both laws of Kirchhoff.

A satisfactory way of drawing the diagrams is to make them large enough so that each resistance, current, and drop in potential may be placed in its appropriate place, with all resistances designated by a certain color, all e.m.f.'s by another color, and all currents by a still different color.

It does not seem desirable to use problems of this type alone in teaching Kirchhoff's laws although, after all, the only difference between them and those commonly used is in the make-up. Shall we give all resistances and e.m.f.'s and let the student solve for the currents, or shall we give some resistances, some currents, and some e.m.f.'s and ask the student to find those that are lacking? Probably a judicious selection of all possible types is best. The purpose of this paper is merely to point out the advantages of the type under discussion which makes it possible to teach the physical principles involved without wasting valuable time on needless arithmetic.

A Laboratory Course in Atomic Physics

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THE systematic teaching of atomic physics has led to the development in Harvard University of a laboratory course for graduate students and seniors of high standing. The experiments are available also to seniors in connection with their tutorial work.

In the *elementary laboratory courses* the student has already learned to take readings, to plot curves and to compare them with formulas representing general laws. Upon progressing to *atomic physics* he encounters a wide gap. After taking his readings he is told to derive statements regarding the quantum orbits of excited atoms that he cannot see and is not even allowed to visualize in a very distinct fashion. The corresponding difficulty turns up in any theoretical course; the student is confronted with such a complicated system of formulas that he loses sight of how completely these formulas are based on experimental facts.

The present course is intended to help the student over this difficulty. For this purpose the student himself derives the final results regarding the properties of atoms and electrons by means of the theory and the experiments which he himself performs. He is not allowed to take some mysterious constant from a textbook to bridge the gap between his instruments and the properties of the atom; theoretical ideas are most satisfactorily established only when the student himself succeeds in deriving the fundamental atomic constants by various independent methods.

Only a very few fundamental experiments of atomic physics lend themselves to class room demonstration. An additional few, particularly spectroscopic ones, can be demonstrated to students individually, and these are adapted to a course of this kind. However, for the most part it is necessary for the students themselves to carry through the experiments.

A list of the experiments follows.[1] In order to

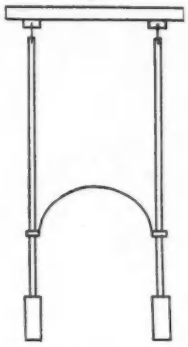

FIG. 1.

FIG. 2.

FIG. 1. Coupled pendulums.
FIG. 2. Cross section of liquid prism, enlarged. The shaded areas indicate the liquid.

bring out the fact that certain apparently independent experiments are closely related by their theoretical ideas, it is necessary to combine experiments in groups such that each group—apart from the inherent value of the individual experiment—yields results on fundamental constants. It will be noted that the older branches of atomic physics as well as recent developments are considered in the course.

I. Gas Theory and Mechanics

1. *Density of air in the gaseous and liquid states.* The weights of a glass bulb, evacuated and also with normal air content, are compared. The density of liquid air is determined in a Dewar flask. (It must be taken into account that commercial liquid air consists almost entirely of oxygen; its observed density must be reduced by the factor 80/100.) High accuracy is not required, since the results are to be combined with those of Exps. I, 3 by applying the approximations of elementary kinetic theory.

2. *Viscosity of water,* by flow through a capillary. This experiment serves as preparation for the one that follows.

3. *Viscosity of air,* by flow through a capillary.[2]

Having determined the pressure p, the densities of air in the gaseous state δ_g and in the liquid state δ_l, and the viscosity of air η, the student computes five fundamental constants (c=most probable velocity, n=number of molecules per cm³ under normal conditions, L=mean free path, σ=radius of the molecule, μ=mass of the individual molecule) on the basis of the following system of five well-known formulas:

$$(1)\quad p/\delta_g = c^2/2 \qquad (2)\quad L = 1/4\sqrt{2}\pi\sigma^2 n \qquad (3)\quad \eta = \tfrac{1}{3}\delta_g c L$$
$$(4)\quad n\mu = \delta_g \qquad (5)\quad n^4\pi\sigma^3/3 = \delta_g/\delta_l.$$

Eq. (5) expresses the approximation that the volume of the liquid equals the total volume of all spherical molecules;[3] Avogadro's number is derived from μ, the value 29 being assumed for the average molecular weight of air.

4. *Relative molecular weight,* method of Dumas.

5. *Relative molecular weight,* method of Victor Meyer.

6. *Relative molecular weight,* by depression of melting point.

7. *Ratio of the specific heats* c_p/c_v, method of Clément and Desormes. (Distinction between monatomic and diatomic gases.)

8. *Mechanical resonance.* The apparatus described by Pohl[4] is used; it is equipped with a larger damping magnet and connected by a reduction gear to a d.c. motor. The connection described by Barkhausen[5] permits a wide variation in speed. The logarithmic decrement is derived from the resonance curve[6] and the result compared with the direct observation. The change of phase at resonance is observed; this is important in the theory of anomalous dispersion.

9. *Coupled pendulums.* Two identical pendulums, suspended on short, flat springs, are used; a variable coupling between them is provided by an adjustable flat spring (Fig. 1). The two slightly different frequencies, superimposed by the coupling in this system, are compared. They are measured by two methods: (1) the oscillations are excited by striking only one pendulum; the frequencies of the oscillations and of the beats are observed; (2) one or the other resulting frequency is isolated by simultaneous excitation of both pendulums, either in the same or in opposite directions.[7] The relation of this experiment to exchange phenomena in quantum mechanical systems is discussed by Mott.[8]

II. Electrons and Ions

1. *Charge of the electron,* by Millikan's oil drop method.[9]

2. *Ratio of charge to mass of the electron,* by the deflection of the cathode ray. The experiment as described by Wiedemann and Ebert, showing the complete circular path of the particles in the magnetic field, is excellent for demonstration. For an accurate measurement the method of Busch is preferable.[10]

From Exps. II, 1 and II, 2 the mass of the electron is computed.

3. *Ratio of charge to mass of the ion,* by the electrochemical equivalent. The *absolute* value of the mass of the ion is to be computed, e being known from Exp. II, 1.

4. *Electric discharge through gases;* the oil pump, the mercury vapor pump, the McLeod gauge, the electrostatic voltmeter. The potential distribution[11] is measured with probes; the space charge is derived from the curvature of the potential-distance curve.

5. *Resonance potential and ionizing potential* of the mercury atom, method of Franck and Hertz.[12] The result is connected with the spectroscopic observation of Exp. III, 5.

6. *Electron emission from a glowing filament.* Only the current-potential curve is observed. A more detailed study

of the glowing filament is made in another course on electron tubes; there the student checks Child's space charge equation and observes the Maxwellian distribution of the electrons emitted from a tungsten filament.

7. *Photoelectric effect:* saturation current, current as a function of the intensity of light. A commercial vacuum cell and an automobile headlight bulb are housed in a long wooden box so that the distance between them can be varied. The inverse square law is used to determine the light intensity at the cell. A set of gauze screens is calibrated.

8. *Photoelectric cell as a photometer:* calibration of a photographic plate (density as a function of the logarithm of the light intensity). First the intensity marks are printed, the intensity being varied by the calibrated gauze screens; after the development the blackening is measured with the photoelectric cell.

9. *Determination of Planck's constant,* from the stopping potential of photoelectrons for various wave-lengths. The experiment described by Suhrmann[13] is simple and instructive although the result is not accurate.

10. *Hall effect.* The electromotive force of the Hall effect[14] in silver is measured. A strip of silver, $1/20 \times 20 \times 50$ mm³, and a small electromagnet with flat pole pieces, providing a magnetic field of 5000 gauss, are used.

III. Spectroscopy

1. *Normal and anomalous dispersion.* A cyanine prism, as recommended by Wood,[15] with an angle of about 1°, is crossed with a 60° flint glass prism. Since only the very edge of this prism, about 2 mm broad, actually transmits light, a greater intensity is obtained by using 5 or 6 thin prisms with edges adjusted parallel. This scheme is realized in a liquid prism, as shown in Fig. 2. In a hollow 10°-prism a group of glass plates, each less than 1 mm thick, are inserted, leaving free space for narrow hollow prisms, to be filled with a saturated solution of cyanine in ethyl alcohol.

2. *Balmer series of the hydrogen atom.* An absolute measurement of wave-lengths is carried through with a concave grating; Planck's constant is derived from the Rydberg constant, $\mathbf{e}$ and $\mathbf{e/m}$ being known from Exps. II, 1 and II, 2.

3. *The series spectrum of the sodium atom,* compared in emission and absorption. This experiment shows the significance of the normal state of the atom. The sources of light are: for the emission spectrum, the carbon arc with anhydrous soda; for the absorption spectrum, the positive crater of the carbon arc. A quartz spectrograph with a prism of fused quartz is used. The absorption tube has been described by Wood.[16] With the absorption tube red hot and a sufficiently long exposure (8 min.) the students succeed in photographing the absorption spectrum to the 17th line; the ionization potential of the sodium atom is computed from the convergence limit of the line spectrum.

4. *The first absorption line of the mercury atom,* observed with the quartz spectrograph. A droplet of mercury in air in a glass tube with quartz windows cemented on with sealing wax is gently heated with a gas burner. Since the resonance potential of mercury, that is, the excitation energy of this line, has been measured in volts (Exp. II, 5), Planck's constant can be obtained from the equation $h\nu = \mathbf{e}V$, $\mathbf{e}$ being known from Exp. II, 1.

5. *Zeeman effect:* computation of $\mathbf{e/m}$ of the electron from the Lorentz theory. A helium discharge tube is placed in a strong magnetic field, parallel to the lines of force. The yellow helium line is observed with a Nicol prism and a Fabry-Pérot étalon. The magnetic field causes a splitting up of the original system of single interference fringes. The field is so adjusted that the outer components of neighboring orders just coincide. This takes place for a field of 5320 gauss if the distance between the silvered plates is 1 cm.

6. *The absorption spectrum of molecular iodine vapor,* observed with a 1-m concave grating or a good prism spectroscope. A glass absorption tube is used, 70 cm long, with a few iodine crystals and air of atmospheric pressure, and a powerful incandescent lamp as source of light. The convergence limit of the molecular vibrations is derived from the observed band spectrum.[17] From this limit the energy of dissociation is computed, the excitation energy of the iodine atom being given as 0.94 volt.

7. *Raman effect.* A glass mercury arc and a tube containing CCl_4 are surrounded by a silvered glass cylinder. The displaced Raman lines can be photographed in a few minutes with an $f:4$ spectrograph.

A special course, offered in alternate years, gives the student an opportunity to become more familiar with spectroscopic technique and line spectra.

IV. Radioactivity

The experiments on radioactivity follow closely the descriptions in Hoag's book.[18]

Experiments on x-rays are demonstrated in a different course. The Brownian movement is demonstrated in the elementary courses.

The student is given an opportunity to satisfy himself that the various methods by which he himself determined the fundamental constants lead to results consistent with one another within the limits of error. These methods are

Charge of the electron: oil drop experiment.
Specific charge of the electron: (1) cathode ray, (2) Zeeman effect.
Absolute masses of atoms: (1) viscosity, (2) electrochemical equivalent.
Planck's constant: (1) stopping potential of the photoelectric effect, (2) Balmer series, (3) comparison of absorption spectrum and resonance potential of the mercury atom.

Brief talks given by the students offer an opportunity for demonstration experiments. Such experiments actually prepared are:

Band spectra: N_2 discharge tube, arc between aluminum electrodes.

Fluorescence radiation of iodine vapor excited by white light.

Wood's resonance spectrum of the iodine vapor excited by the green mercury line.

The spectroscopic displacement law: arc spectrum of Zn, showing an intense triplet, compared with the spark spectrum, showing an additional intense doublet.

No student carries through the complete program just described. Yet such a long list of experiments is needed in order to adapt the program to the previous training of the individual student. Not every student, for example, is prepared to perform the experiments on band spectra.

Some of the experiments, although carried through with high precision in research, cannot be performed with great precision by students during a few afternoons. This is not considered to be a serious objection, since the students have ample opportunity for making precise measurements in other courses; for instance, in electrical measurements, optics, and spectroscopy. Whenever the choice must be made, it seems preferable for the student to obtain more or less rough results with apparatus that he himself can arrange than to obtain more accurate values with apparatus permanently assembled and adjusted.

The course which has been described is not complete. We intend to add new experiments, particularly, simple ones which introduce the student to the ideas and techniques of the final more difficult experiments. However, the main objective of the course will remain the same; namely, to make the student familiar with the close relation between experiment and theory prevalent in modern physics.

References

[1] Two books have been published recently that present an excellent description of numerous laboratory experiments: J. B. Hoag, *Electron Physics*, Van Nostrand, 1929; and G. P. Harnwell and J. J. Livingood, *Experimental Atomic Physics*, McGraw-Hill, 1933.

[2] B. L. Worsnop and H. T. Flint, *Advanced Practical Physics for Students*, 2nd Ed., Methuen, 1927, p. 174; W. Watson and H. Moss, *A Textbook of Practical Physics*, 3rd Ed., Longmans, Green, 1930, p. 146.

[3] O. E. Meyer, *Kinetic Theory of Gases*, Longmans, Green, 1899, p. 318.

[4] R. W. Pohl, *Mechanics and Acoustics*, Blackie and Son, 1932, p. 254.

[5] H. Barkhausen, Phys. Zeits. **13**, 1131 (1912).

[6] G. W. Pierce, *Electric Oscillations and Electric Waves*, McGraw-Hill, 1920, p. 71. The theory of dispersion (the atom as electric resonator excited by the light wave) is discussed in R. W. Wood, *Physical Optics*, 3rd Ed., Macmillan, 1934, p. 480.

[7] W. Kossel, Phys. Zeits. **32**, 172 (1931).

[8] N. F. Mott, *An Outline of Wave Mechanics*, Cambridge Univ. Press, 1930, p. 91.

[9] J. B. Hoag, *Electron Physics*, p. 20.

[10] E. Wiedemann and H. Ebert, *Physikalisches Praktikum*, 6th Ed., Friedr. Vieweg und Sohn, 1924, p. 503; H. Busch, Phys. Zeits. **23**, 438 (1922); cf. J. B. Hoag, *Electron Physics*, p. 50.

[11] E. Wiedemann and H. Ebert, *Physikalisches Praktikum*, p. 501.

[12] J. Franck and G. Hertz, Ber. d. D. Phys. Ges. **16**, 457 (1914).

[13] R. Suhrmann, Phys. Zeits. **33**, 579 (1932).

[14] E. H. Hall, Phys. Rev. **26**, 820, 1925. The apparatus is simplified so as to demonstrate only the Hall effect.

[15] R. W. Wood, *Physical Optics*, 3rd Ed., Macmillan, 1934; Phil. Mag. **1**, 624 (1901). "Cyanine Gruebler" (Quinoline Blue), Eimer and Amend, New York.

[16] R. W. Wood, Astrophys. J. **29**, 97 (1909).

[17] R. Mecke, Ann. d. Physik **71**, 104 (1923). J. Franck, Trans. Faraday Soc. **21**, Part 3 (1925); Zeits. f. physik. Chemie **120**, 144 (1926).

[18] Reference 1.

ALCHEMY may be compared to the man who told his sons he had left them gold buried somewhere in his vineyard; where they by digging found no gold, but by turning up the mould, about the roots of their vines, produced a plentiful vintage. So the search and endeavors to make gold have brought many useful inventions and instructive experiments to light.—FRANCIS BACON.

THE history of a science is the science itself.—GOETHE.

A PARADOX is never terrifying to the scientist. Faraday wrote to Tyndall, "The more we can enlarge the number of anomalous facts and consequences the better it will be for the subject, for they can only remain anomalies to us while we continue in error."—GILBERT N. LEWIS, *The Anatomy of Science.*

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

Equipotential Lines in a Conducting Sheet

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FOR the study of the distribution of equipotential lines and lines of flow in an electrically conducting sheet, the carbon plate illustrated in Fig. 1 is superior in many respects to the apparatus usually employed which depends upon electrolytic conduction.

The top view of this plate W is shown in the upper part of Fig. 1 and the cross section in the lower part. Heavy deposits of copper were made electrolytically on the plate at T_1, T_2, and C. The terminal T_1 was deposited completely across one end of the plate both front and back. T_2 is a 5/8-inch circular terminal slightly larger than the binding post used to make contact with it. To minimize edge effects around C, a square hole was cut in the carbon plate extending approximately half-way through the plate; the copper deposit fills this depression and extends considerably above it. A is a circular hole cut completely through the plate. Since the carbon plate has a low resistance it was found necessary to minimize the effects of contact resistance by soldering the copper strips S_1 and S_2 to the copper terminals. The binding posts P_1 and P_2, through which the current enters and leaves the plate, are held by machine screws which pass through the plate. The binding posts P_3 and P_4 are connected to a series of 10 equal resistances as explained below.

The dimensions of the plate are indicated by the cross-ruled lines which are spaced 1 in. apart. The lines are of white lead, sufficiently thinned with turpentine to be applied with a ruling pen. The thickness of the plate is 0.17 in. The frame for the plate consists of Formica strips, F, around the edge of a rectangular sheet of transite, B. The numbers of the lines were burned into these Formica strips and intensified with flake white.

Current of about 2 amp. is furnished by the storage battery B (Fig. 2) through a resistance R. Most of this current goes through the low resistance plate but part of it goes through 10 equal resistances in series, r_1, r_2, etc. With a moderately sensitive galvanometer G (such as Leeds and Northrup Type P) connected as

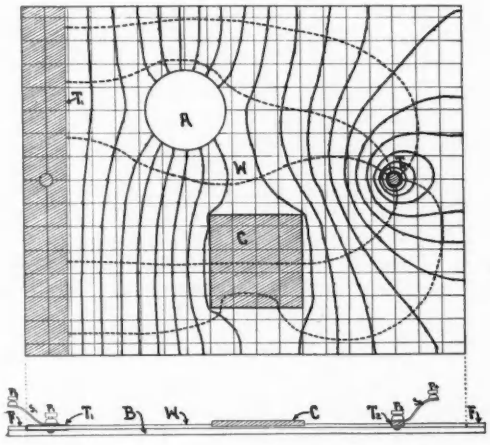

FIG. 1. Top view and cross section of apparatus.

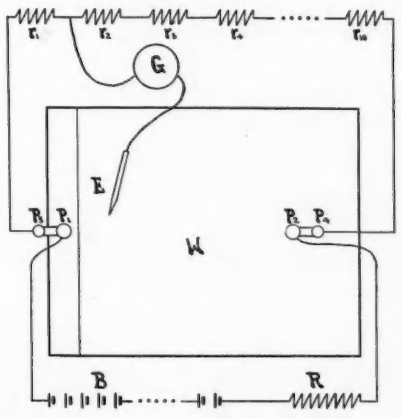

FIG. 2. Schematic diagram of apparatus, showing method of taking observations.

shown, several positions of the exploring electrode E are found for which the galvanometer gives zero deflection. The coordinates of the points are read from the cross-ruled lines on the carbon plate. These points are plotted on cross-section paper and connected by a smooth curve. Similarly curves are drawn with the galvanometer connected to each of the other points between resistance coils.

We now have a series of equipotential lines in which the difference of potential between consecutive lines is 1/10 of the total drop across the plate and the field is of course inversely proportional to the distance between the lines. The equipotential lines in Fig. 1 were constructed in this manner except that two resistance boxes were substituted for the 10 series resistances and the resistances so chosen that the potential difference between consecutive lines was 1/20 of the total drop. The five representative lines of flow, indicated by broken lines, were sketched freehand. For routine laboratory work it is not necessary to plot so many lines nor to locate so many points on each.

This experiment is considered to be of value only for those students who are willing and able to study the resulting curves carefully and interpret them fully. The average of the reciprocal of the distance between consecutive lines together with the resistance of the plate and its effective cross section area between these lines may be used by the better students to determine the resistivity of the carbon; this of course is not the best method of determining the resistivity but is an interesting and instructive exercise.

I wish to acknowledge the assistance of Mr. H. P. Schott who took the data for and constructed the curves of Fig. 1 as an exercise in the elementary laboratory course.

Accessories for Portable Spectroscopes and Spectrometers Used in Undergraduate Instruction

A. N. Lucian, *Randal Morgan Laboratory of Physics, University of Pennsylvania*

Optical instruments used in the undergraduate laboratory are necessarily of an inexpensive grade of manufacture and in most cases lack the conveniences and refinements of standard equipment. To conduct large classes with such apparatus often calls for the exercise of a good deal of ingenuity and improvization on the part of the instructor. For these reasons, certain improvements which we have made in our equipment may prove to be of interest to undergraduate teachers in general.

The Improved Spectroscope

1. The telescope tube is provided with a simple bayonet catch A, Fig. 1, instead of being fastened to the main frame of the instrument in a more or less permanent manner. This enables the student to detach the telescope tube in an instant, focus it for infinity and replace it quickly; and it insures that the engraved line near the objective end of the telescope will coincide exactly with the index mark on the frame, so that the telescope occupies identically the same position every time.

2. The slit end of the collimator tube is provided with an extra shield, made of a convenient length of brass tubing, and fastened to the fixed portion of the slit frame B, Fig. 2. This shield extends beyond the plane of the slit for a distance of at least 2.5 cm. In addition, there is placed within the shield and immediately in front of the slit a very thin disk of transparent mica. These additions circumvent the students' irrepressible tendency to set the Bunsen burner so close to the instrument that the heat seriously damages the jaws of the slit.

3. The third addition consists of a lighting unit for the scale end of the spectroscope, consisting of a 1.5-volt flashlight bulb, a dry cell, and a pushbutton switch, all arranged in such a way that the student can read the scale of the spectroscope readily by pressing a button. The switch is mounted on one of the legs of the tripod base. The dry cell is held in strong clips fastened to the

vertical pedestal of the instrument. The bulb is mounted within a tubular housing fastened rigidly to the arm of the spectroscope which carries the scale. The entire illuminating unit is shown at *C* in Fig. 1.

Sources of Light

The sources of light to be studied with the spectroscope and spectrometer are arranged in our laboratory in the following manner.

1. A Bunsen burner with either a sodium or a sodium-lithium attachment is placed within an asbestos-covered sheet iron tube about 40 cm high and 10 cm in diameter, *D*, Fig. 2. Three vertical slots of suitable dimensions are cut on the cylindrical surface of the tube so that 3 students can work simultaneously with a single source of light. Close to the bottom end of the tube are drilled a number of small holes to provide ventilation for the Bunsen burner. A number of these units are installed permanently in the laboratory and the students bring their instruments to them.

2. A mercury vapor lamp of medium size is mounted in a vertical position and concentrically within a sheet iron tube about 90 cm high and 30 cm in diameter, *E*, Fig. 2. Six vertical slots are cut on the cylindrical surface of the tube. This unit is mounted permanently in the center of a suitably shaped table, so that 6 students can observe the mercury spectrum at the same time without interfering in the least with one another.

3. Neon glow lamps of commercial type, working directly from the 110-volt line, are mounted on stands and provided with protective covers, as shown at *N* in Fig. 2. These units are not permanently fixed but are brought out of storage and placed at convenient locations in the laboratory for temporary use.

4. For the study of other spectra, such as those of hydrogen, helium and argon, Geissler tubes on specially constructed tripod mountings, *G*, Fig. 2, are placed in convenient locations for the duration of the laboratory period. The students move their spectroscopes around to the various tubes and take their observations in rotation, with a minimum of congestion and confusion. The tubes are driven by means of old-fashioned induction coils but plans are under way to operate them from ordinary commercial transformers of the type used with neon signs. This will eliminate the troubles inherent in the use of induction coils and will give a remarkably steady source of light; the change in the method of excitation will not produce any appreciable change in the nature of the spectra produced, as far as elementary instruction is concerned.

The improvements described in this paper are so simple and inexpensive that any laboratory could adopt them with little effort and thus add to its efficiency in teaching elementary optics.

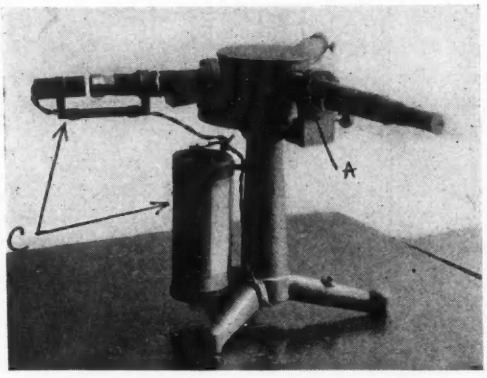

FIG. 1. *A*, bayonet catch; *C*, method of illuminating scale.

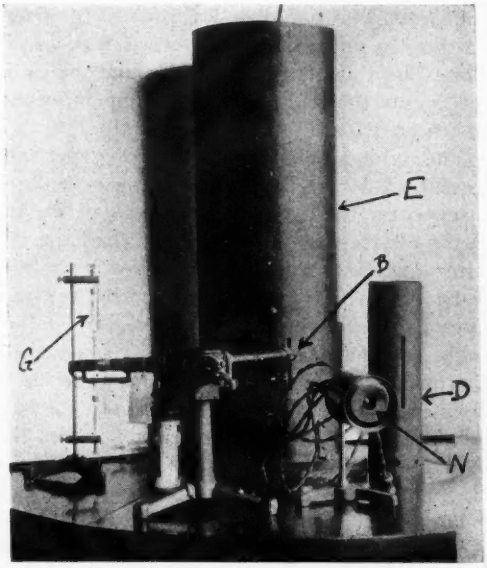

FIG. 2. *B*, slit-shield; *D*, Bunsen burner unit; *E*, mercury vapor lamp unit; *G*, Geissler tube; *N*, neon lamp unit.

Electric Timers and Motors for Laboratory Use on Alternating-Current Circuits of Constant Frequency

E. L. HARRINGTON, *Department of Physics, University of Saskatchewan*

THE wide-spread use of controlled-frequency alternating currents which accompanied and made possible the general use of electric clocks also has favored and led to the development of several new laboratory instruments. The present paper describes two that have been developed and used in our laboratory. While they involve no basically new principles and may differ but little from similar devices developed elsewhere the writer is not aware of any published accounts of them.

THE ELECTRIC TIMER

Fig. 1 shows a timing device that consists essentially of only three simple elements—a synchronous motor, a non-slipping clutch and a counter. Eight of these timers, built in this laboratory, have proven to be so reliable, trouble free and "fool proof" during the past two years that a brief description would seem to be appropriate.

In practice the motor is started by the hand and left running during the period of its use. To time any event one merely throws in the clutch at the beginning of the event, and out at its close. The difference between the final and initial readings of the counter gives the time in seconds to one or two decimal places, directly.

The coil has 2500 turns of No. 30 copper wire, wound on a core built up of transformer iron sheets cut in the form indicated. The middle half of these were cut 12 mm shorter than the two outer quarters, so that the latter form pole pieces, two at each end, separated by the same distance as the teeth on the rotor. The support angle bracket *K*, was cut from a brass sheet approximately 3 mm thick, and has at each end elevated horizontal leaves to which the pole and coil assembly is bolted. This bracket carries also the axle of the rotor, and is rubber insulated from the wooden base to ensure a quiet operation.

The rotor itself consists of a toothed disk mounted on a suitable bearing. It was made from sheet iron approximately 6 mm in thickness, and cut out by boring a circular row of holes and then joining the holes with the help of a saw. It was made with 12 teeth in order to obtain 10 r.p.s. on a 60-cycle current. (It may run at half this frequency if not given the proper speed when started.) In some cases the rotor was provided with a belt groove (Fig. 1) in order to make it possible to use the timer also as a constant speed motor. Both ball bearings and plain phosphor bronze bearings have been tried; the former have less friction, but the latter are easier to construct, run more quietly and apparently are just as serviceable. The motor takes approximately 0.2 amp. on a 110-volt a.c. circuit.

To design a satisfactory clutch proved to be the most difficult problem, as it is necessary that it have little inertia, that it start the counter without any drag when engaged, and that there be no after-spin when disengaged. All these requirements are met in the comparatively simple design finally adopted. A short hollow

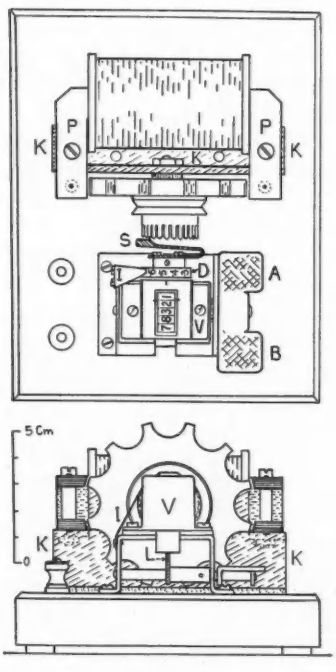

FIG. 1. Top and front views of timer and motor.

brass cylinder is mounted directly on the rotor and its free end made into a circular "comb" by saw cuts about 3 mm deep. A phosphor bronze spring mounted transversely on the shaft of the counter is so bent and shaped that its free end runs between a pair of cylinder teeth so long as the counter is in its forward, engaged position. The design is such that there can be neither binding due to clutch pressure or to imperfect alignment, nor any slipping whatever. The counter is mounted on a sliding plate and is moved forward by pressing *A* and backward by pressing *B*. A short lever, *L*, which is mounted on the shaft of the key *AB*, transmits its motion to the sliding plate by means of a leaf spring that serves also to keep the plate firmly against its bed. As soon as *B* is pressed down a spring, *I*, strikes the rotating disk and positively prevents any after spin of the countershaft.

The counter is a commercial Veeder counter registering revolutions, which means that its readings are directly in tenths of a second. The brass disk, *D*, mounted on the shaft of the counter, is stamped to read in hundredths of a second, though ordinarily this is not used in laboratory experiments. An attempt to use reset counters was abandoned as they are rather noisy, require more power and involve the possibilities of errors from backlash in resetting. Besides, better readings are likely to be obtained if the student does not know the result until he has subtracted one reading from another. It is obvious that such a device might be used also as a counter to determine an unknown frequency in case the power and frequency available are suitable to run the motor.

In one of the timers constructed here a Telechron clock motor, type BC (Warren Telechron Company, Ashland, Mass.) having a gearing which gives its shaft 1 r.p.s., was used with a counter giving 10 counts for each revolution of its shaft. This timer has the advantage that it requires no starting, is quieter, and greatly simplifies the problem of construction. On the other hand, the margin of power is rather narrow, and the self-starting feature is not an unmixed blessing, for in the case of an interruption of the power service one might not be made aware of it, whereas with the first type any interruption sufficiently long to affect the count would stop the motor, and it would remain stopped.

The advantages of these timers arise chiefly in the elimination of starting and stopping errors so characteristic of stopwatches and clocks. They are less fragile, and therefore involve less trouble and expense. The accuracy of the master clock ultilized in controlling the frequency of a city power circuit is likely to be of much higher order than that of a laboratory stopwatch or stopclock. The timer gives the entire time in seconds directly. While it is less portable than a stopwatch, for laboratory classes there is something to be said in favor of this feature.

The Synchronous Motor

This device is merely the motor part of the timer, mounted on a brass tube so as to be conveniently clamped on laboratory support rods. A pulley is substituted for the toothed cylinder. Such a motor is useful for operating devices in which constancy of speed or exactness of time intervals is of prime consideration, and where small power is required. To illustrate, one of these motors has been used with great success in a research problem in physical chemistry in which the operation of a stirrer at constant speed was most essential. They can be used to operate shutters, to give pulses to chronograph styli at intervals of, say, 0.1 or 0.01 second, to give signals at exact and controllable intervals, and to open and close switches, valves or cocks in a cyclic manner. As constructed for the timer, the motors have a speed of 600 r.p.m. but within limits they may be constructed as readily for any other desired speed by suitably altering the number of teeth on the rotor.

It is hoped that some manufacturer soon will make more conveniently available to laboratories a small, reasonably priced, synchronous motor of conventional design, as it would have more power and be self-starting. In the meantime the motor described here may find many important uses.

The writer is greatly indebted to Mr. A. H. Cox, our instrument maker, for his skilful and painstaking cooperation in the development of this apparatus.

A Simple Spectrometer for Use in the Elementary Laboratory

R. W. McLachlan, *Department of Science, New Jersey State Teachers College at Montclair,*
and F. R. Johnson, *Newark, New Jersey*

SERIOUS difficulties are encountered in the use of the conventional type of spectrometer by first year students. If many individuals are to work simultaneously the cost of a sufficient number of instruments becomes excessive. Proper manipulation of such an instrument by inexperienced students requires almost constant supervision. Most important is the fact that many students fail to comprehend the significance of the manipulations which they have been directed to perform. The purpose of this paper is to describe the construction and some uses of a tested apparatus that obviates these difficulties.

Details of construction are shown in Figs. 1 and 2. A metal disk D, 5 in. in diameter, cast with a shoulder and fitted with a screw for clamping to the rod of a ring stand or support, serves as the prism table. A burner support of the flat disk type may be used. The triangular prism holder B is constructed by mortising and gluing together three strips of wood. The base of the holder is a triangular sheet of 1/32-in. brass. A tall form, 28×75-mm equilateral glass prism P is inexpensive and quite satisfactory. A thin strip of wood held against the base of the prism by means of two small helical springs prevents accidental shifting of the prism. A 3/16-in. brass bolt b serves as the axis of rotation for the prism holder and the arms A and A'. A brass washer between the disk D and the prism holder provides sufficient clearance to allow the prism holder to be rotated readily. Two brass protractors, graduated in degrees, are riveted to the disk D to form a completely graduated circle about 9 cm in diameter (Fig. 1).

The supporting arms A and A' are strips of hard wood. The inner portion of each arm is 20 mm in thickness at a point near the periphery of the prism table and is beveled from this point to the inner end in order that the arms may be turned sufficiently close together. The cross-sectional dimensions of the outer portions are 8×28 mm. Metal pointers M and M', attached to the arms, extend inward to the graduated portion of the protractor. Brass plates, 1/8 in. in thickness, attached to the arms by means of countersunk bolts, provide the necessary bearing surfaces. Set-screws W and W', threaded through the brass plates, when tightened prevent accidental shifting of the arms.

The double convex lenses L and L' are 7.5 cm in diameter and have a focal length of approximately 17.5 cm. A similar lens e of diameter 3.75 cm and focal length 5 cm forms the eyepiece of the telescope. The lens holders and screen supports are of a type commonly used to mount optical systems on meter sticks.

The screen S, containing a vertical slit 0.15 ×30 mm, is a 10×10-cm piece of 28-gauge sheet iron coated on both sides with black asphaltum paint. A similarly blackened metal sheet, S', supports the cross hairs. Excellent cross hairs can be made from unspun silk fibers, held to the metal plate by bits of sealing wax. More durable but otherwise less satisfactory ones may be made from iron wire (36-gauge or finer) coated with black paint.

A set of apparatus is provided for each group of two students. The students are required to

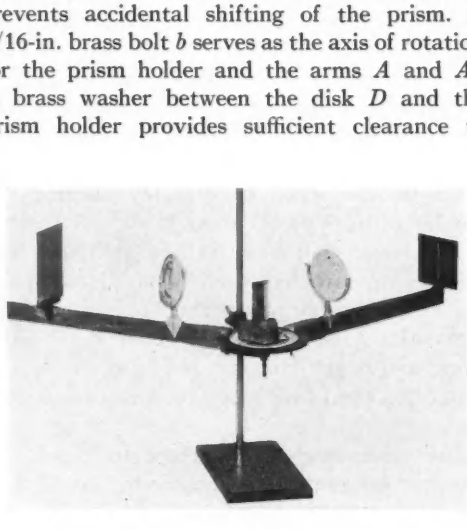

FIG. 1. Photograph of simple spectrometer.

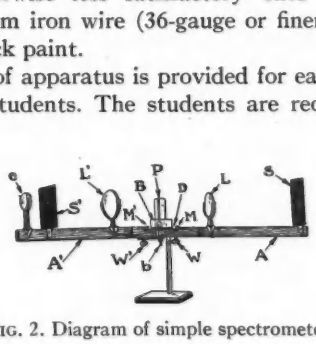

FIG. 2. Diagram of simple spectrometer.

assemble the optical system by placing the prism, lenses and screens in their appropriate positions, and to make the necessary adjustments. As a first exercise the image of the slit is received on a white cardboard screen (Fig. 1). After the correct position of the telescope arm has been thus approximated the image is readily observed when the eyepiece and cross hairs are mounted. The instrument may be adapted to a variety of uses, including measurement of the angles of a prism, measurement of the angle of minimum deviation for monochromatic light, determination of the index of refraction of glass and demonstration of spherical and chromatic aberration.

The large size of the parts and the open structure of the instrument facilitate manipulation and promote understanding of the functions of the lenses, slit and cross hairs. Lenses of small ratio f/d have been purposely chosen, in spite of the fact that they possess large optical defects. Experience has proven that unskilled observers are able to locate the image much more readily when lenses of relatively large diameter are used. Furthermore, the use of such lenses in conjunction with a relatively long slit provides an excellent demonstration of spherical and chromatic aberration in a practical situation; the significance of these phenomena is thus emphasized.

A Simple Telephotophone for Communication on a Beam of Light

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DURING the past three or four years there have been several newspaper accounts of successful experiments on the transmission of speech and music by means of a beam of light; yet relatively little information has been published concerning the methods employed in this novel mode of communication. Although the idea is as old as the telephone itself, the modern development of sensitive amplifiers and photoelectric cells has enhanced its possibilities, and the radio has accentuated the need for private point-to-point signalling to supplement the more general "broadcasting." The present paper describes a simplified device for accomplishing light-beam transmission. It is suitable for lecture demonstration purposes, and presents some features which suggest its usefulness over long optical paths. "Telephotophone" is proposed as an appropriate name for a mechanism which enables one to telephone on a beam of light.

All experiments in this field utilize essentially the same receiving apparatus; namely, a photoelectric cell, with or without a collecting reflector, coupled to a high-gain amplifier and loudspeaker. There is not the same uniformity in the transmitting apparatus. The essential requirement, in any case, is a means of modulating a source of light so that the variations in its intensity correspond to the amplitude of voice currents generated by a microphone and amplifier system. Alexander Graham Bell[1] reflected a beam of light directly from the vibrating diaphragm of a microphone upon a selenium cell. During the late war, an acetylene manometric flame method was developed and utilized successfully for infrared signalling over several miles.[2] More recently, a favorite practice has been to modulate the output of a neon crater glow discharge tube, a method which affords high quality of transmission but which lacks sufficient intensity for use over long ranges.[3, 4] A modification of this method, presumably employing an electrodeless discharge in mercury vapor, has been used successfully over moderate distances.[5] Ramsey describes a simple and effective application of a speaking arc light.[6]

The present apparatus operates by means of a mechanical light-valve driven by a magnetic speaker unit. Voice currents from a microphone, phonograph pickup, or radio are sent into an

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[1] A. G. Bell, Am. J. Sci. **20**, 305 (1880).
[2] T. W. Case, J. O. S. A. **6**, 4, 398 (1922).
[3] C. O. Browne, Wireless World and Radio Rev. p. 240, Mar. 5 (1930).
[4] Walker and Lance, *Photoelectric Cell Applications*, p. 70.
[5] E. E. Free, Pop. Sci. **122**, 37, Apr., (1933).
[6] R. R. Ramsey, Science **78**, 105 (1933).

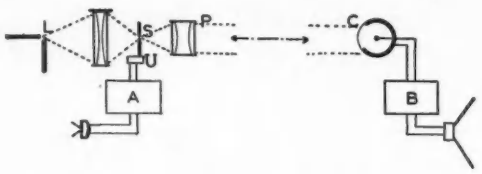

FIG. 1. Schematic plan of telephotophone system.

audiofrequency amplifier *A*, Fig. 1. This amplifier drives the magnetic speaker unit *U*, to which is connected one vane of a variable slit *S*. Light from a *steady* source *L* is focussed upon this slit and the width of the slit governs the quantity of light passing through to the projection lens *P*. The lens *P* focusses an image of the slit upon a distant photoelectric cell *C*; here fluctuations in the quantity of light received by this cell cause corresponding variations in the photoelectric currents which actuate the amplifier *B*. A loudspeaker reproduces the original signal.

Fig. 2 shows the construction of the telephotophone mechanism. The drive stem of the magnetic unit from a cone loudspeaker is connected directly by a collar and set-screw to a movable brass vane which slides in polished guides. The stationary vane forming the other side of the slit *S* is provided with an adjusting screw to secure proper width of the slit for optimum modulation. Variations in this width are caused by the motion of the magnetic-unit armature. When the light gate *S* is in operation, its vibration may be felt with the tip of the finger, and a faint reproduction of the message is heard at the transmitting end. In practice, for short distances within the laboratory or lecture room, a 6–8-volt, 32-cp. automobile headlight bulb operated by a storage battery is entirely adequate. For greater distances it is necessary to use a stronger source, such as a steady carbon arc operating on direct current. The author has even used sunlight reflected upon *S* by a heliostat.

At the receiving end, the loudness of the signal depends chiefly upon the amplification employed. If the light signal is very weak, it may be difficult to bring the signal level above the noise level of the photoelectric cell and amplifier *B*. For long spans it is desirable to collect more of the signal light by placing the photoelectric cell at the focus of a parabolic mirror. By using a carbon arc as light source, however, the author has communicated successfully more than 1000 feet without the use of such a collecting reflector. Since a large part of the current passing through the photoelectric cell depends upon the general illumination falling upon the cell, whereas the signal strength depends upon *variations* in the quantity of light coming from a distant source, it is essential to use a variable grid-bias on the control grid of the first amplifier tube at the receiving end. The operator at this end may thereby adjust the mean grid voltage to a suitable value for good amplification despite wide variations in the intensity of general illumination.

The method of modulation described here presents certain advantages over methods previously used. *First*, for demonstration purposes, the device allows the student to see clearly how the light intensity is varied in accordance with the original sound. It illustrates the application of several fundamental principles of talking motion pictures applied to the problem of communication over an optical path. The demonstration is striking; one feels like a magician when one can stop the transmission of a message merely by interposing some opaque object in the path of the light.[7] *Second*, the device allows

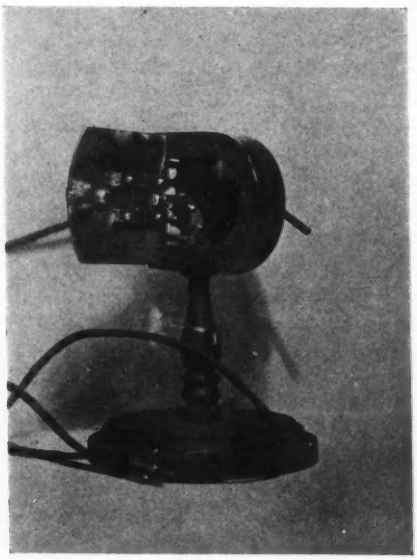

FIG. 2. Light gate mechanism of telephotophone.

the use of an intense light source, and imposes upon the transmitted light a larger percentage of modulation than is possible with other high-intensity methods. *Third*, the device controls the quantity of light transmitted from a *steady* source, in contrast to all previous methods which depend upon varying the output of the source itself. It shares with other light-sound systems the ability to transmit point-to-point communication with a high degree of secrecy which may be still further enhanced by the use of invisible radiation. Photoelectric cells are in general more sensitive to ultraviolet light than to visible; but atmospheric absorption of ultraviolet light constitutes a serious limitation upon its usefulness. Infrared radiation penetrates the atmosphere better than either ultraviolet or visible; but photoelectric sensitivity drops off in this region of the spectrum. However, infrared transmission through more than a kilometer of dense sea fog has been reported.[8]

It is still questionable whether the use of light-beam communication will compete successfully with ultra-short wave radio in the short range, point-to-point field on account of the serious handicap of atmospheric absorption of light signals. However, the freedom of the light system from tuned radiofrequency circuits is in its favor; and for moderate ranges, up to 5–10 mi., it may easily become an important extension of present radio practice. The telephotophone described herein leaves much to be desired in the way of fidelity of reproduction; fidelity is sacrificed for simplicity of construction. By using a string galvanometer type of light valve, similar to that employed in one kind of talking motion picture recording,[9] the quality of transmission should be materially improved without sacrificing the principle of mechanical modulation of a steady light source.

It is a pleasure to acknowledge the assistance of Mr. Franklin K. Fite in much of the experimental work.

[7] A clear musical note may be made at the loudspeaker-end by holding a vibrating tuning fork just in front of the slit *S*.

[8] F. Michelssen, Zeits. f. tech. Physik **11**, 511 (1930).

[9] D. MacKenzie, Bell Tech. J. **8**, 173 (1929).

The A. A. P. T. Committee on Membership

A preliminary report received from the Committee on Membership indicates that remarkable progress already has been made. So far there are over 200 new members as a result of its activities. The object has not been to conduct a campaign in the ordinary sense or to urge membership upon anyone, but merely to acquaint every eligible person with the purposes and activities of the Association.

The Chairman reports that the number of teachers of physics in secondary schools who are eligible for membership is rather small and that it is best to have them approached by those Association members who are best acquainted with their qualifications and interests. Everyone is urged to assist the Committee by reporting names of such eligible teachers.

A Committee report for the current year will appear in the February issue. The personnel of the Committee has not been completely determined, as some who formerly were unable to assist in the work have recently become active. Those who have been responsible for the increase in membership to September 1st, are as follows: Homer L. Dodge, University of Oklahoma, *Chairman;* A. A. Bless, Univ. of Florida; Henry L. Brakel, Univ. of Washington; F. L. Brown, Univ. of Virginia; Edna Carter, Vassar College; R. C. Colwell, West Virginia Univ.; Thomas D. Cope, Univ. of Pennsylvania; David W. Cornelius, Univ. of Chattanooga; G. K. Daghlian, Connecticut College; L. E. Dodd, Univ. of California; L. A. DuBridge, Washington Univ.; W. H. Eller, Illinois State Teachers College; H. W. Farwell, Columbia Univ.; E. F. George, Texas Technological College; D. V. Guthrie, Louisiana State Univ.; Lloyd B. Ham, Univ. of Arkansas; John Harty, Missouri State Teachers College; George R. Harrison, Massachusetts Institute of Technology; Ellis Haworth, Eastern High School, Washington, D. C.; C. W. Heaps, Rice Institute; L. L. Hendren, Univ. of Georgia; R. M. Holmes, Univ. of Vermont; Harley Howe, Cornell Univ.; J. L. Hundley, Univ. of North Dakota; Wilfrid J. Jackson, Rutgers Univ.; F. E. Kester, Univ. of Kansas; K. Lark-Horovitz, Purdue Univ.; Homer L. LeSourd, Milton Academy; O. C. Lester, Univ. of Colorado; Noel C. Little, Bowdoin College; C. J. Lynde, Columbia Univ.; H. H. Marvin, Univ. of Nebraska; Paul McCorkle, Pennsylvania State Teachers College; Frank C. McDonald, Southern Methodist Univ.; Will V. Norris, Univ. of Oregon; R. A. Porter, Syracuse Univ.; Catherine Rittler, Goucher College; R. A. Rogers, Park College; R. D. Rusk, Mt. Holyoke College; O. W. Silvey, A & M College of Texas; Francis G. Slack, Vanderbilt Univ.; W. W. Sleator, Univ. of Michigan; K. K. Smith, Northwestern Univ.; N. F. Smith, The Citadel; A. K. Steunenberg, College of Idaho; G. W. Stewart, State Univ. of Iowa; O. M. Stewart, Univ. of Missouri; G. R. Tatum, Baylor Univ.; L. W. Taylor, Oberlin College; E. H. Warner, Univ. of Arizona; D. L. Webster, Stanford Univ.; T. R. Wilkins, Univ. of Rochester; Jay W. Woodrow, Iowa State College; Anthony Zeleny, Univ. of Minnesota.

DISCUSSION AND CORRESPONDENCE

On Physics in Relation to Medicine

THE report of the committee appointed to make a study of physics in relation to medicine[1] deserves strong commendation, and should go far toward putting physics on the same plane in the eyes of medical students and medical men that chemistry and biology have long occupied.

About seven years ago I became greatly interested in this question, and visited a number of institutions on this continent and also in Europe. I was amazed at the general indifference towards physics shown by those outlining courses for premedical and medical students, though there were here and there men outstanding in their interest and success in the applications of physics to medicine. Here in the University of Saskatchewan we have given since that time a *second* course in physics to those premedical students who have had only a one-year general Arts course in this subject.[2] Our experience strongly supports the view that such a course should be a fixed requirement. It is highly approved not only by the medical faculty, but also by the students; they like it, and not because of any attempt to make it a snap course but rather on account of its obviously basic importance. A number of our students who are now doing more advanced work in another institution were asked to appraise this course in the light of their subsequent work and reported it as outstanding in value among the premedical courses taken.

I would take exception to the point of view reported by the committee, though not as its own, of those who "feared that greater emphasis on the physics in the curriculum would lead to an over-estimate of the value of physical instruments in medical practice." Would they on the same grounds fear chemistry lest it instill too much confidence in drugs and laboratory tests? Surely a scientifically trained medical man should let his basic training and the fundamental requirements in any case demanding his attention, dictate as to whether chemical or physical measures or a combination of them are to be employed.

The backwardness, even timidity, shown by many medical men in the recognition and use of physical measures in their practice is explicable only on their lack of confidence in their own ability as physicists. Certainly a well-trained research worker in any science would never hesitate to use the most effective means to a desired end, regardless of whether such means are classified as physical, chemical or biological. How far would physiology have progressed had the elements of physics been eliminated from it? Obviously the only logical cure for this indefensible attitude, and for the general lack of confidence in physics on the part of medical men, is to make sure that their training in physics is just as adequate for their needs as is their present training in biology and in chemistry. *Such training cannot be given in less than two years, and this much time must be found*—even though it be taken from the other sciences of chemistry and biology. But one could justify additional training in physics merely on its value as a foundation in chemistry, biology and physiology, for all of these sciences are growing more physics-like in their points of view, basic theory and methods. Physics may or may not be on a par with chemistry in its importance to the medical man, but certainly its relative importance is greater than the usual ratio of courses, say one to three or four, would indicate.

I can scarcely believe that anyone who has had any experience in giving a special course in physics to premedical students would concur with the suggestion of the committee that no such course is needed. The committee does insist on having small groups in the laboratory and in the quiz and conference groups. Surely the obviously rational plan would be to place the premedical students in one of these groups. In my mind no other plan can be supported on educational or other grounds except possibly economic, and the latter is not seriously involved since in most universities one must have sections whatever plan is followed. The whole future as well as the immediate preparation of the physician is fundamentally scientific and it is most unreasonable that the only course planned for him in the basic science, physics, should be one so thinned down that a heterogeneous group of Arts students can make the grade in it. I have a very strong conviction that if only one year in physics is to be given, the group of premedical students should be handled separately.

The better plan would be to allow the students to take the general course in accordance with the present practice, preferably in the first year so that the student will be in a better position to successfully pursue his courses in the other sciences. This should be followed by a second course, highly specialized, but yet sound and basic physics. Such a plan would make it possible to eliminate a large number of students who enter the university with a hazy idea that they are "going in for medicine" but who are unwilling to meet the exactments of such a course, or unable to stand the pace that must be set. With the unfit eliminated in the first course the instructor should be able to go far in the second one. The latter course, coming later, could be more effectually correlated with the other basic as well as with the medical sciences.

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[1] Am. Phys. Teacher **2**, 48, 101 (1934).
[2] For a discussion of our point of view, and an outline of the course, see E. L. Harrington, J. Ass'n Am. Med. Coll. **7**, 362 (1932).

The Time-Item Ratio in College Physics Tests

OUR third mid-semester examination in college physics for the fall semester of 1933 consisted of 50 items of the same type and difficulty as those used in the Cooperative Tests of January and May, 1933. It was given to 130 students and 16 of these volunteered to participate in an experiment on the amount of time that should be allowed for answering such tests. At the end of the 45-min. period, which is the time ordinarily allowed for these 50-item tests, the 16 students were given red pencils and permitted to continue work for a second period of 45 min. They were told not to alter any of the answers recorded during the first period but to continue the examination until satisfied that they had done their best; if the response chosen for any item during the second period was different from that previously chosen, both responses were to be indicated, one in red, the other in black. The results are given in Table I. The average score for the 130 students was 17.9.

TABLE I. *Number of correct responses.*

First period	Second period	Gain	First period	Second period	Gain
6	6	0	18	25	+7
14	14	0	19	23	+4
14	16	+2	21	36	+15
15	12	−3	22	19	−3
15	11	−4	24	23	−1
15	16	+1	24	29	+5
17	17	0	25	26	+1
18	18	0	32	33	+1

The average for the 16 students was 18.69 for the first period of work and 20.25 for the two periods of work, giving an average gain for the second period of 1.56.

The student who raised his score 7 points during the second period was a professor of physical education who was taking the course without credit. The one who raised his score 15 points turned out to be a graduate student who admitted that he did not try his best during the first period but worked at an average rate of speed during the two periods. If he is not counted the average gain for the 15 students for the second period drops to 0.53.

It is to be noted that by working the second period, 4 students decreased their scores, 4 of them failed to improve them, and 8 increased them, 3 of the last group by one point only. This test had half as many items and required half as much time as the Cooperative Test used in January and May, 1933.

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On Ohm's Law

WHILE Ohm's study of the relation of current to difference of potential in an electric circuit included showing that the resistance of a conductor is proportional to its length and inversely proportional to its cross-sectional area, what is commonly known as Ohm's law expresses only the experimental fact that the ratio of difference of potential between any two points of a linear conductor to the current is a constant, called *resistance*, as long as the physical state of the conductor is unchanged and there is no e.m.f. between the points in question. When there is an e.m.f. between the points the law states that $(V_1-V_2\pm E)/i$ is a constant. For steady currents the constancy of this ratio has been tested over a very wide range of values and, in the case of metallic and electrolytic conductors, is found to hold as accurately as observations can be made. The observations of Bridgman[1] of an increase in resistance at a current density of the order of 10^6 amp./cm^2 in silver and gold was not confirmed by Barlow[2] for gold and platinum up to a current density of 2×10^6 amp./cm^2.

For variable or alternating fields the question becomes whether $(V_1-V_2\pm L di/dt)/i$ is a constant. It is known that the resistance is not the same as for steady currents, that there is a skin effect, with the current not distributing itself uniformly through the conductor. The associated change in resistance is small for small wires and low-frequency currents and, as it does not depend on the current strength, it may still be argued that Ohm's law holds. For fields above 30,000 volts/cm applied to electrolytes for short intervals of time M. Wien[3] has found increasing conductivity, or diminishing resistance; changes of over 50 percent are observed with fields up to 300,000 volts/cm. An effect of the frequency of the field at high frequencies is also known, but again Ohm's law holds within the error of observation over a very wide range.

For gases the ratio under consideration is so inconstant that in certain circumstances an increase of potential difference accompanies a diminution of current, and the definition of resistance at a point as dV/di leads to a conception of negative resistance. This evidently falls entirely outside Ohm's law.

With these facts in mind it seems unfortunate that so many textbooks give the impression that the law of Ohm always holds for *steady* currents, since this is not true if a gas forms part of the circuit, and that they imply that it does not hold for variable fields, for which it actually is valid over a wide range, the exceptions occurring for very strong fields or for high frequencies.

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[1] Bridgman, Proc. Nat. Acad. Sci. **7**, 299 (1921).
[2] Barlow, Phil. Mag. **9**, 1041 (1930).
[3] Wien, Ann. d. Physik **83**, 327 (1927); **85**, 794 (1928).

Laboratory Investigation *versus* Laboratory Verification

VARIOUS methods have been tried to create more interest in elementary physics, especially in the laboratory work, and various names have been given to some of these attempts, such as "project method," "unit method" and "type studies." Each method has stimulated much more interest in certain phases of physics than has the older and more formal method of using the laboratory to verify laws and principles; and as a result students continue to show an average performance on standard tests, despite the fact that these tests presuppose a

knowledge of material not covered in these special methods. The chief disadvantage of the new methods is that much less subject matter is covered than is rightfully considered as prerequisite for entrance to the more advanced courses.

The method to be discussed here represents an attempt to obtain many of the advantages of the new methods without losing the scope of the standard elementary courses. In the belief that the primary objective of elementary physics should be the development of the ability to reason from past experiences to what would happen under new or varied ones, the method involves laboratory work designed to teach students to recognize important observations and to use them to predict general laws and principles; each experiment thus becomes a project which furnishes the "directed experience" needed to understand some law or principle. These experiences are to be followed by the study of a textbook that gives the conclusions of some well-known scientist who has made similar experiments. Finally, accurate and lasting impressions of the principles are obtained by solving problems.[1]

Some indication of the probable effectiveness of the method is given by a study made by Dykes[2] of the question of whether or not laboratory work should precede the recitation in the presentation of subject matter. Ten groups of high school students from 7 cities in 6 different states participated in the study. Five experiments in mechanics and a similar number in heat were employed. Five of the schools presented mechanics by the "laboratory first" (*Lf*) method and heat by the "recitation first" (*Rf*) method, whereas the remainder employed the reverse procedure. A summary of the results appears in Table I.

TABLE I. *Comparison of "recitation first" (Rf) and "laboratory first" (Lf) methods. The data represent average grades.*

Subj.	Meth.	Thurman intell. test	Teacher's monthly tests	Dyke's test	Teacher's lab. grades	Teacher's term grades	Delayed test
Mech.	*Rf*	134.55	77.51	74.16	80.52	79.23	76.98
	Lf	131.44	79.53	76.03	79.92	81.13	79.88
Heat	*Rf*	131.44	80.29	75.35	82.48	80.03	76.51
	Lf	134.55	78.88	77.44	78.53	80.12	77.20
Av.	*Rf*	133.00	78.90	74.75	81.50	79.63	76.74
	Lf	133.00	79.20	76.73	79.22	80.62	78.54
Diff.		0.00	0.30[1]	1.98[1]	2.28	0.98[1]	1.80[1]

[1] Difference in favor of *Lf* method.

There follows a brief summary of the conclusions made from the study:

1. There is a measurable difference in favor of the *Lf* method with regard to the facts observed in the laboratory, the observed relation among these facts, the development of reasoning ability, and interest shown in laboratory work.

2. For the immediate-recall tests, the combined average for both mechanics and heat is only slightly in favor of the *Lf* method.

3. The results of the delayed tests in both mechanics and heat indicate that the *Lf* method is superior for students of all grades of intelligence.

4. The results of the immediate-recall tests, delayed tests, term averages, and interest shown reveal that more definite and permanent results are obtained by the *Lf* method.

5. The average laboratory grades are definitely lower for the *Lf* method, which is to be expected, since students usually work more slowly when uncertain of the results to be obtained. However, the term grades, which include the laboratory grades, are higher for this method in both mechanics and heat. Other results were also obtained which indicated that training in this method helps a student later on to do more accurate and thoughtful work by the *Rf* method.

6. Of 70 students who gave reasons for prefering one method or the other, 43 stated that they preferred the *Lf* method because it was much easier to get the lesson for the next day; the remaining 27 felt that this method made the laboratory work too difficult to complete in the alloted time.

It should be said that this study was carried out with ordinary laboratory apparatus, some of which is too complicated for satisfactory use in the *Lf* method; for the beginner the apparatus should be simple enough to make its manipulation obvious but at the same time it must be capable of yielding data accurate enough to reveal the law or principle sought. Several types of apparatus have been designed by us to meet this requirement.

Other advantages of the "laboratory first" method that cannot be measured by any of the standard tests now in use are: it develops the ability to discern crucial tests for laws or principles, gives training in establishing methods of correlating various types of data, encourages reliance upon one's own observations in forming judgments, and develops the ability to reason independently. Any of these would seem to be of more value to the student than the memorizing of the facts in any number of textbooks.

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[1] The basic features of this method are described in Sch. Sci. and Math. **29**, 627 (1929).

[2] C. Dykes, Thesis for the Master's degree, George Peabody College for Teachers, 1932.

On the Teaching of Magnetism

CONSIDERATION of the case which Warburton[1] and Webster[2] make for the use of the Amperian point of view in the teaching of magnetism to elementary classes seems to be complicated by two non-essential features of Warburton's argument: his allegation that use of the pole treatment leads to a contradiction with experiment, and his proposed modification of the *physical content* of the definition of H (not simply its *mode* of definition). All the more because the present writer feels much sympathy with the arguments advanced for the use of the Amperian treatment as being more in harmony with modern theories, and probably more teachable, he feels impelled to comment on these points. As to the first point, concerning the alleged contradiction between experiment and Coulomb's law with μ in the denominator (Warburton, page 2, col. 1) this law applies to the case of point poles in an infinite homogeneous medium with constant μ; that it must not be applied to the interactions of extended magnets has been

clearly brought out by Wilberforce,[3] and its use where *pieces* of magnetic matter are concerned is simply a misapplication of the theory. This law leads to no contradictions when properly applied, but we must agree that it does not appear to be very useful. The permeability, introduced (as Warburton indeed says) "for the purpose of describing the behavior of the medium," does just that by appearing in the denominator; explicit consideration of the induced poles in the medium itself is necessary only if one wishes to find out why it must appear there.

The field quantity which Warburton designates by H differs essentially from the traditional H of electromagnetic theory in that it receives contributions from conduction currents alone; hence many of his statements are not true of the traditional H, and might mislead the casual reader. The statements that "$B=H+aI$, where $a=4\pi$ only in the case of an infinitely long, uniformly magnetized bar" and that "Inside iron within a solenoid, H is the magnetizing field due to the solenoid alone" (Warburton, page 5, col. 2) are typical of those referred to. Now the classical theory provides two modes of treatment, *identical in content*, for problems involving magnetized matter; one proceeds from div I (I = intensity of magnetization) and suggests the use of the magnetic-pole concept; the other proceeds from curl I, which is equivalent to, and may be visualized as, a current density (Warburton's i_m). Perhaps the reason for the desire to change the definition of H is the fact that this quantity is particularly germane to the first of these treatments, and does not appear so naturally when the second is used exclusively. However, it still possesses considerable advantages not enjoyed by H_W (Warburton's H), particularly that both the equations $B=\mu H$ and $H=kI$ (k = susceptibility) may be retained as describing the behavior of the magnetic medium at a point, with μ depending only upon the medium, and perhaps H. On the other hand, μ_W (Warburton's μ) would depend on the geometry of the whole apparatus, rendering the situation far less simple. The simplicity, directness, and utility of the Amperian treatment would be in no wise diminished by defining H by the equation $H=B-4\pi I$, B already having been defined in terms of force per unit length per unit current, or of e.m.f. In any case, it seems to be out of the question that H_W and μ_W, differing as they do from the quantities designated by H and μ in the classical theory, should receive the latter symbols, for endless confusion would inevitably result. The same considerations apply to D_W and ϵ_W.

It seems to be unfortunate that Warburton's presentation is made in terms of the orbital motions of electrons, since modern theories teach us that the magnetism of iron is due practically exclusively to orientation of their spins. However, as Warburton points out in a footnote, this does not constitute any real obstacle to the presentation of the theory from the Amperian point of view. In this connection it is interesting to note that a treatment by Weizsäcker,[4] based on the Dirac theory of the electron (according to which the electron is to be pictured, if at all, as a current whirl), leads one to regard B as the field within iron which will govern the deflections of fast charged particles shot through it, although recent experiments of Alvarez,[5] in which β-particles were used, require a field definitely less than $B/3$, and perhaps equal to H. A purely pedagogical point which may have some importance is the difficulty one will have in applying a magnetic theory which lacks Coulomb's law, as does the formulation being discussed, to the interactions of magnets, or of magnets and magnetic fields, in any *quantitative* way. When one is permitted to use field theory, he can of course derive this law as a purely mathematical consequence of the fundamental laws, and use it as a convenient mode of calculation, but in an elementary course it would have to be brought in without justification, if at all. To omit the usual problems involving the calculation of field strengths due to magnets would not be a serious matter, but one is reluctant to give up this law entirely.

The writer wishes to express his sincere appreciation to Professor Warburton and Professor Webster for having sent him replies to an earlier draft of this letter, in consequence of which it has taken its present improved form.

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[1] F. W. Warburton, Am. Phys. Teacher **2**, 1 (1934).
[2] D. L. Webster, Am. Phys. Teacher **2**, 7 (1934).
[3] L. R. Wilberforce, Proc. Phys. Soc. **45**, 82 (1933). See also L. Page, Phys. Rev. **44**, 112 (1933).
[4] C. F. v. Weizsäcker, Ann. d. Physik **17**, 869 (1933).
[5] L. Alvarez, Phys. Rev. **45**, 225 (1934). See also W. F. G. Swann and W. E. Danforth, Jr., Phys. Rev. **45**, 565 (1934); these authors come to a conclusion opposite to that of Alvarez, but their problem is more complicated than his, since they used cosmic-ray particles of originally unknown energies.

THE correspondence to which Professor Van Lear refers so kindly in the foregoing letter, and also discussions with other physicists, suggest a note here on the evidence as to the reality of Amperian currents. The fact that Ampere's theory explains most of the common phenomena of magnetism at least as well as the pole theory is of course familiar to all physics teachers, whether or not they have special interests in this field. Equally familiar are the facts that Ampere's theory explains diamagnetism, on which the pole theory fails, and that paramagnetism and the Zeeman effect also are associated with circulation of electricity. But to the practical-minded student the important question about Amperian currents is whether they explain the magnetism of iron.

Fortunately, however, there is good evidence even on this question, in the Barnett and Einstein-de Haas effects: magnetization of iron by rotating it, and the converse effect, respectively. Barnett's careful researches[1] have proved that the elementary magnets in iron and other ferromagnetic metals have the dynamical properties of gyroscopes. Furthermore the proof is quantitative, giving the ratio of angular momentum to magnetic moment, and in all these metals this ratio is about 5 percent greater than that calculated for a spinning electron. Since orbital motion of electrons, without spin, would make this ratio twice as great, these researches gave the first evidence, and probably the best, that ferromagnetism is to be ascribed primarily to electron spins, but with a minor contribution from orbital motion. Furthermore Sucksmith[2] recently has

found the Einstein-de Haas effect even in paramagnetic substances. Some of these also owe their magnetism primarily to electron spins; but others show considerable fractions of it to be orbital. This difference is of special interest in confirming many of Van Vleck's[3] theoretical predictions on these ratios and thus proving the essential similarity of electron spins and orbits in their gyroscopic properties.

Strictly speaking, of course, one cannot nowadays picture a spinning electron literally as a sphere on which we may watch the electricity go around. But neither is it possible to take the orbits literally. Both are below the Heisenberg limits of determinacy. Even so, it would be obviously absurd to try to picture orbital magnetization in terms of poles; but the spin is so much farther below the Heisenberg limits that one can expect it to stray much farther from the classical picture, and the suggestion is often made that it might as well be pictured in terms of the pole theory. One might, for example, even "explain" the Barnett effect by assuming the elementary magnet to be a pair of opposite magnetic poles fastened at a finite distance apart on a rigid frame, with a static electric charge between them, because Lorentz's theory of electromagnetic momentum would indicate gyroscopic dynamics for such a system. But this means postulating two kinds of field-producing particles, where Ampere's theory needs only one. Either model being a concession to our need for something to visualize, the model that spins is not only the simpler one, but certainly the one more suggestive of gyroscopic properties and of the similarity in these properties between spins and orbits.

Turning from such direct evidence as the Barnett effect to the more abstruse quantum mechanics, we must consider Dirac's relativistic electron. This is often misconceived as a resurrection of the old magnetic poles, because the term "dipole" has often been applied to it for lack of any other equally short name for something with a magnetic moment. Actually, however, its magnetic moment and its angular momentum appear together as consequences of Dirac's relativistic equations,[4] with their values the same as for a classical spinning electron. And in Weizsäcker's[5] application of Dirac's theory to the field within iron, the interaction between any moving electron used to measure this field and the spinning electrons producing it is expressed in terms of the operator used for the mutual-inductance energy of two currents, whereas there could never be any mutual energy between currents and poles. In other words, the best readily visualized approximation to the Dirac electron is the classical spinning electron.

In the classroom the use of this modernized Amperian theory has interesting consequences. Some of these are discussed in my recent paper[6] and another is suggested by Van Lear's remarks, above, on the status of problems on Coulomb's law as applied to magnets. As he says, one cannot derive this law from the laws for currents without going farther into mathematics than one can go in the elementary classroom. This fact in itself, however, may be considered significant of the place Coulomb's law for magnets occupies in the logical structure: it is far from fundamental. To give the student the clearest understanding of magnetism, therefore, it may indeed be just as well not to risk overemphasis of such a secondary law by having problems on it in the first course. And for the same purpose, a part of the time saved by their omission can be used very profitably for a talk on the Barnett effect, with demonstrations of the behavior of a gyroscope in a rotating frame.

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[1] S. J. Barnett, 1909 to date, summarized in Physica **13**, 241 (1933).
[2] W. Sucksmith, Roy. Soc. Proc. **A128**, 276 (1930); **A133**, 179 (1931); **A135**, 276 (1932).
[3] J. H. Van Vleck, *Electric and Magnetic Susceptibilities*, Ch. IX. Oxford University Press, 1932.
[4] P. A. M. Dirac, *Quantum Mechanics*, Oxford Univ. Press, 1930, Ch. XIII.
[5] C. F. von Weizsäcker, Ann. d. Physik **17**, 869 (1933).
[6] Webster, Am. Phys. Teacher **2**, 7 (1934).

PROFESSOR VAN LEAR, above, and others have called attention to a point in my paper that may be expressed more clearly. We all agree that one may correctly deny that the usual Coulomb law applies to extended physical magnets. The points of view differ in that the one seeks to justify its use in elementary teaching regardless, and the other chooses to face and emphasize the difficulties as they appear in the light of the very simple logic of the elementary student, the logic we must not discourage him from using. For example, the student is taught that the pole is the fundamental quantity in the end of a physical magnet, and that the Coulomb expression with μ in the denominator is the fundamental law and was discovered by experiments with physical magnets. His problems, calculating fields and forces, are applied to physical magnets. The contradiction now appears in that the student is told, when the point comes up for discussion, that this supposedly universal and fundamental law does not apply to his physical magnets and indeed "does not appear to be very useful." In the case of the physical magnet and the piece of soft iron, explicit consideration either of Amperian or atomic currents on the one hand or induced poles on the other, is necessary. When the soft iron is in the form of a thin sheet, the attraction on a second magnet may indeed be increased or decreased depending on the position of the sheet. When the demagnetizing effect of regions 2, Fig. 1, in my paper,[1] is predominate the energy magnetizing the iron must come at the expense of the magnet, which therefore may be said to be weakened. When the sheet is placed close to the face of the first magnet the self-magnetizing effect of iron and magnet partially counteracts this weakening.

The classical theory, in addition to B, calls for three kinds of magnetic field H because of the mixture of modes of treatment: (a) the field of conduction currents which is solenoidal, div $H=0$ everywhere;[2] (b) the "demagnetizing field of induced poles" H'', derived from a scalar potential and for which curl $H''=0$ everywhere while div H'' departs from zero at the poles; and (c) the sum of (a) and (b), the conventional field H' for which curl H' is not zero

where there are currents and div H' is not zero at the induced poles.

One may indeed obtain the field of a closed conduction current (a) from a scalar potential corresponding to the equivalent magnetic shell. But any vector derived from a scalar potential has zero curl, and one finds $\int H_s ds = 4\pi i/c$ in this case only by omitting the field within the shell.[3] That is, one chooses to retain the solenoidal properties of currents, curl $H = 4\pi j/c$, and at the same time use the scalar potential which demands curl $H = 0$. A complete shift to pole analysis would include also making div H not zero at the shell, but one avoids stressing this point since it is frequently desirable to use the vector potential which demands div $H = 0$ everywhere. This partial shift to the pole mode of treatment should be regarded as a convenient fiction.

The Amperian point of view consists in treating an atom as a rotation of electricity in a closed path, thus making its field, like that of a conduction current, solenoidal. According to this mode of treatment the field aI of a collection of atoms, if the distribution of Amperian currents be known, is found by addition, like that of a collection of coils; and it is solenoidal, like B, making div $aI = 0$ everywhere. A retention of the classical field H', which includes H'' and involves div H' differing from zero, is a partial retention of the pole mode of treatment and makes a discontinuity in H' at the ends of the bar of soft iron, even if one describes the iron using curl I. H' in $B = H' + 4\pi I$, $B = \mu H'$, and $I = kH'$ in the short rod assumes uniform magnetization where the iron is not uniformly magnetized. The supposed advantage of retaining these equations here is greatly reduced by the necessity of adjusting H' to fit. The correction for this erroneous assumption of uniform magnetization made by adjusting H' (presupposing knowledge of the distribution of poles) fitted in very well with pole theory but does not fit in Amperian theory. In restricting the field within iron to H, nothing new is added; H'' is replaced by the self-magnetizing fields, and H' may be allowed to fall into disuse. This restriction avoids the inference that there is any magic H' orienting the atoms to form a definite B irrespective of the extent of the aid of the surrounding atoms. A recently revised authoritative text[4] states that H' "must be regarded as purely artificial." Use of this artifice draws attention directly away from, rather than toward, the physical explanation that the alignment of magnetic atoms in the iron varies widely from place to place, and so confuses the picture.

The permeability μ, in Eq. (16) of my paper[5] and classically as well, is defined for the ideal case of uniform magnetization. With H restricted to conduction currents the ratio B/H is dependent on geometry and is equal to μ only for the ideal case. Eliminating three obvious errors which unfortunately slipped in when I rewrote my paper for the purpose of condensing it, the sentence including Eq. (18) and the fine print below it should be replaced by:

> Substituting Eq. (16) in Eq. (15) we find
>
> $$I = (\mu - 1)B/4\pi\mu. \qquad (18)$$
>
> For a uniformly magnetized sphere, the partial field, aI, is found, by integrating the surface density of i_m over the surface, to be $8\pi I/3$. Including $a = 8\pi/3$ in Eq. (17) and substituting in Eq. (18), $I = [3(\mu-1)/(\mu+2)](H/4\pi)$, and for B corresponding to $\mu \gg 1$, $B = H + 8\pi I/3 = 3H$. There is thus no necessity for postulating a "demagnetizing" field.

As an example, suppose a sample of iron in a Rowland ring magnetizes to $B = 1000$ gauss in an applied field of $H = 10$ gauss so that $\mu = 100$. If now we adjust an applied field H with the same kind of iron in a sphere until $B = 1000$ gauss as in the ring, then, using the same I in $B = H + 8\pi I/3$, we find $H = 340$ gauss. One may indeed compute an H' in an artificial Kelvin drill hole surrounded by inverse Amperian currents by $H' = H + 8\pi I/3 - 4\pi I = 10$ gauss or by $H' = B/\mu$, and div H' differing from zero then only approximates the continuous but rapidly varying field as one emerges from the end of the drill hole. This artificial H', however, plays no rôle like the applied $H = 10$ gauss in the Rowland ring in persuading the atoms to orient themselves. H acts on the atoms where they are; the H' as defined by the drill hole is not defined where the atoms are, nor even in the end of the drill hole.

It should be pointed out that the variable field aI of Amperian currents represents a value averaged over a cross section and the factor a should not be considered as a scalar when B, H and I are not parallel vectors. Also $a = 4\pi$ in certain other symmetrical cases, notably when i_m has the same configuration as i.

There are many advantages in partially adopting the Amperian point of view even if one is reluctant to depart from the classical field H', but making all magnetic fields solenoidal appears to be a decided gain in simplicity and self-consistency not only in elementary teaching but in the general mathematical theory as well. Mason and Weaver's treatment of magnetism permits and encourages this interpretation.

The inverse cube expressions for the magnetic field on the axis and in the bisecting plane of a short magnet, the field on the axis of the long ideal magnet, and also the torque on an ideal magnet, may be obtained very simply from Amperian currents without use of the calculus. The Coulomb expression may then, if desired, be developed readily though not rigorously by the assumption that the torque may be considered due to forces on artificial poles.

Finally, the restriction of the meaning of D to the electric field due to an ideal distribution of "free" charge makes it identical with Richtmyer's F in his development of Maxwell's waves.[6] Thus in a medium of constant ratio $B/H = \mu$, the wave equation is obtained directly using these simple definitions of the fields.

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[1] Warburton, Am. Phys. Teacher **2**, 1 (1934).
[2] Mason and Weaver, *The Electromagnetic Field*, Eqs. (108, 109), p. 186; p. 199; and B, Theorem 3, p. 355.
[3] Page and Adams, *Principles of Electricsty*, pp. 258–259.
[4] Abraham-Becker, *Classical Theory of Electricity and Magnetism*, p. 138, Eng. tr., 1932.
[5] Reference 1, p. 5.
[6] Richtmyer, *Introduction to Modern Physics*, p. 90.

Brief Notices of Recent Publications

First Year College Physics

Review of Pre-College Mathematics. C. J. Lapp, Associate Professor of Physics, F. B. Knight, Professor of Educational Psychology, and H. L. Rietz, Professor of Mathematics, University of Iowa. Pp. 124+iv. Figs. 61. Paper cover. Scott, Foresman and Co., Chicago, 1934. $1.00. A carefully prepared work-book which provides explanations of and drills in the skills that a college freshman needs in order to be equipped mathematically to enter college physics, chemistry and mathematics. Its contents having been determined by actual analysis of the requirements of first courses in colleges and extensive study of student disabilities in mathematics of the type reported recently by Lueck [Am. Phys. Teacher **2**, 18 (1934)], the book represents a real contribution to the literature and material of physical science teaching and is a good example of what can be accomplished by competent specialists in subject-matter fields and in education when they work cooperatively. The major topics treated are: linear equations, substitution, statistical and formula graphs, ratio and proportion, variation, simultaneous equations, quadratic equations, areas and volumes, logarithms, and some elements of geometry and trigonometry. With each topic there is a section of carefully constructed drill material, space for the student's work, and an answer key. The book should be especially useful to students who are weak in the basic skills needed for a successful mastery of college physics.

Physics for Medical Students. J. S. Rogers, Senior Lecturer in Natural Philosophy, University of Melbourne. Edited by T. H. Laby. Pp. 205+x, Figs. 71. Humphrey Milford, Oxford University Press, London, 1933. 11*s.* 6*d.* net. This book, intended to supplement the treatment of physics given in standard textbooks, is a praiseworthy and very successful attempt to show the importance and relations of physics to medicine and thus make the study of the science more interesting and profitable for medical students. It contains excellent chapters on osmosis, the colloidal state of matter, blood pressure, maintenance of body temperature, conservation of energy in the human body, resonance theory of hearing, ultraviolet light, the microscope, hydrogen ion concentration, high-frequency currents, radioactivity, and therapeutic use of x- and γ-rays. The more difficult sections and certain sections intended for reference only are marked with asterisks. The book originally represented an extension in scope of a pamphlet prepared in 1921 by E. O. Hercus and T. H. Laby; it has twice been revised and enlarged.

Physics in the Building Industry. R. E. Stradling. Pp. 24, Figs. 11. Institute of Physics, 1 Lowther Gardens, Exhibition Road, London, S.W. 7. Paper cover, 1/1 postpaid. The twentieth of a series of lectures on "Physics in Industry" given before the Institute of Physics. Other lectures in the series, each available at the same price, deal with physics in relation to the glass industry, the food industry, photography, the utilization of fuel, the development of the internal combustion engine, sound recording, and meteorology. Some of the lectures have been published in variously priced cloth-bound editions by the Oxford University Press; these deal with physics in relation to mechanical engineering, electrical engineering, ceramics, textiles, metallurgy, the rubber industry, agriculture, aeronautical science, and navigation.

Intermediate and Advanced Physics

The Thermodynamics of Electrical Phenomena in Metals. P. W. Bridgman, Hollis Professor of Mathematics and Natural Philosophy, Harvard University. Pp. 200+vii. Figs. 33. The Macmillan Co., New York, 1934, $2.50. The substance of 16 papers published by the author during the past ten years on interrelations of a thermodynamic character between various electrical properties of metals. The first 38 pages of the book are devoted to an illuminating examination and discussion of the fundamentals in this field.

The Method of Dimensions. A. W. Porter, Emeritus Professor of Physics in the University of London. Pp. 80 +vii, Figs. 9. E. P. Dutton and Co., New York, 1933. $.85. An outline of some of the applications of the theory of dimensions.

Physical Constants. W. H. J. Childs. Pp. 77+viii. E. P. Dutton and Co., New York, 1934. $1.20. An up-to-date and well-arranged pocket-size collection of physical constants and tables, selected for the use of students from standard books of tables and from recent textbooks and papers. Brief mathematical tables are included.

History and Biography

Sir Isaac Newton's Mathematical Principles of Natural Philosophy and His System of the World. Florian Cajori, Late Professor of the History of Mathematics Emeritus, University of California. Pp. 680+xxxv. University of California Press, Berkley, 1934. $10.00. A revision of Andrew Motte's classical translations of the third edition of the *Principia* (1726) and of *The System of the World* (1728). Parts of the text have been rendered into modern phraseology, but without detracting from the charm of the original. There is a 54-page appendix of interesting historical and critical notes. This is Professor Cajori's last work; it was edited after his death by Professor R. T. Crawford. The typography and binding are excellent.

Philosophy of Science

The Philosophy of a Scientific Man. Paul R. Heyl, U. S. Bureau of Standards. Pp. 182. Vanguard Press, New York, 1933. $1.50. Little that is original, but a well-ordered summary of philosophical thought as it bears on the intellectual needs of the scientific man of mature outlook. A consideration of the validity of the "extrapolation of mind into nature," concluding that reason is limited to conscious life, rejecting the conception of a God both omnipotent and benevolent, yet expressing a faith in "Something better we may hope to sense, of which we may feel ourselves a part."

The Limitations of Science. J. W. N. SULLIVAN. Pp. 307+v. The Viking Press, New York, 1933. $2.75. Recommended for the intelligent layman who seeks to gain some understanding of the fundamental generalizations of science, and their modifications in recent years. Only one of the eight chapters is devoted to the "Limitations of science"; others deal with the expanding universe, the mystery of matter, the scientific account of origins, the nature of mind and the values of science. Mr. Sullivan is an Englishman whose hobbies are music and mathematics; he is the author of *Three Men Discuss Relativity*, of a work on Beethoven, and of various other books and essays on music and popular science.

SCIENCE TEACHING

An Introduction to the Teaching of Science. ELLIOT ROWLAND DOWNING, Department of Education, The University of Chicago. Pp. 258+vii. University of Chicago Press, Chicago, 1934. $2.00. A complete rewriting of the author's *Teaching Science in the Schools* (1925). Considerable attention is given to the physical sciences. The chapter on "Skill in Scientific Thinking" is particularly good.

Science Teaching at Junior and Senior High School Levels. GEORGE W. HUNTER, Lecturer in Methods of Education in Science, Claremont Colleges. Pp. 552+viii, Figs. and graphs 21. American Book Co., New York, 1934. $2.50. A comprehensive digest of the more recent findings in education as they apply to science teaching in the secondary schools, with extensive, classified lists of references to the periodical literature on science teaching. The author was formerly head of the department of biology in De Witt Clinton High School, New York.

MISCELLANEOUS

The Photographic Darkroom. Its Arrangement and Use. E. J. WALL. Pp. 107+iv, Figs. 12. American Photographic Publishing Co., Boston, 1933. $1.50. A useful handbook, replete with practical directions for arranging, equipping and maintaining the darkroom.

A Manual of Thesis-Writing. ARTHUR H. COLE, Professor of Business Economics, Harvard University, and Karl W. Bigelow, Professor of Economics, University of Buffalo. Pp. 48+vi. Figs. 2. Paper cover. John Wiley and Sons, New York, 1934. $.75. An outline of methods of procedure in collecting data and writing the results of inquiries, and a compilation of accepted rules and usages helpful in the preparation of scientific papers. Gives many references to books and papers on the same subject.

Romping Through Physics. OTTO WILLI GAIL. Pp. 64, 103 drawings by Hermann Blank. Alfred A. Knopf, 1934. $1.50. A fascinating little book for children, with many interesting applications of mechanics and heat to everyday phenomena. Attractive printing and gayly colored drawings.

Modern Alchemy. WILLIAM ALBERT NOYES, University of Illinois, AND W. ALBERT NOYES, JR., Brown University. Pp. 207+viii, Figs. 17. Charles C. Thomas, Springfield, Ill., 1932. $3.00. Modern ideas of the constitution of matter, valence, effects of radiation on chemical changes, new elements, and medical chemistry, discussed from the point of view of the chemist.

Numerology. E. T. BELL, Professor of Mathematics in the California Institute of Technology. Pp. 187+vii. The Williams and Wilkins Co., Baltimore, 1933. $2.00. In this engaging little book, a distinguished mathematician takes advantage of the fact that he is connected with a scientific institute and lives within a stone's throw of Hollywood to pursue the question of whether there is "more science in numerology than there is numerology in science." *Numerology* is used by Professor Bell in a very general sense to mean all the varieties of doctrines, from Pythagoras onward, that ascribe mystic meaning and peculiar power to numbers. Numerological thought, he avers, abounds in mathematics; isomorphism and extrapolation are examples of the numerological fallacy, which may be typified by the statement that a map is not the thing mapped. "Because some [mathematical] theory makes correct predictions in three or three hundred instances is no evidence that it is more than a fictitious scaffolding of imaginary and unnecessary lumber. Insofar as anyone believes the contrary, to that extent is he a numerologist in the traditional sense of the Pythagoreans. . . ." Because there are only 9 chapters in the book, whereas *10* is the philosophically perfect number, the author has supplied an appendix of parlor tricks and other substitutes for fudge making.

Teaching Aids

PAMPHLETS AND TRADE LITERATURE

Frequency Measurements at Radio Frequencies. Pp. 58, Figs. 29. Bull. 10. General Radio Co., Cambridge, Mass. Gratis. Principles and methods of frequency measurements.

The Light Benders. Pp. 47, Figs. 52. The Bausch and Lomb Optical Co., Rochester, N. Y. Gratis. Some elementary facts of applied optics, in an attractive booklet.

The General Radio Experimenter. General Radio Co., Cambridge, Mass. Gratis. A monthly trade bulletin which contains information on electrical communication technique and its applications in allied fields.

Kirchhoff's Laws. Cumulative Unit System Laboratory Experiments in Physics, C-55. Pp. 9, Figs. 12. Central Scientific Co., Chicago, Ill. Gratis. One of a series of pamphlets on laboratory experiments with simplified and standard apparatus. The series has been discontinued but copies of this pamphlet are still available.

Vision—The Eye and How We See. Pp. 9. The Better Vision Institute, 205 East 42nd St., New York, N. Y. Gratis. This small folder, which can be obtained in quantities for distribution to students, contains reproductions, in colors, of many of the diagrams on the structure of the eye, action of lenses, etc., that appear on the large charts distributed by this organization [Am. Phys. Teacher **1**, 120 (1933)]. The diagram of the prismatic spectrum on one of the charts contains several errors which have been corrected in this folder.

DIGEST OF PERIODICAL LITERATURE

Contributors: Donald K. Berkey, G. A. Van Lear, Jr. The Editor is responsible for unsigned articles

Apparatus, Demonstrations and Laboratory Practice

The removal of water marks from negatives. Alfred L. Monner; *Am. Phot.* **28**, 566, Sept., 1934. Strain in the gelatine emulsion is relieved by use of two solutions: (1) water, 16 oz., anhydrous sodium carbonate, 1 oz.; (2) water, 16 oz., 28-percent acetic acid, 0.5 oz., potassium alum, 1 oz. Place the negative in *1* and warm the solution to 90°F by setting the tray in a larger tray of warm water. Next place the tray in another large tray containing water at about 60°F until the solution and water have reached the same termperature. Now take the negative out of *1* and rinse it thoroughly in this same tray of water. Solution *2* and the rinse water must now be brought to the same temperature, whereupon the negative may be transferred to *2*. After a few minutes immersion the negative may be washed thoroughly and hung up to dry. Guard against sudden temperature changes in the process to prevent reticulation, and watch carefully while in solution *1* to avoid frilling or blistering. D. K. B.

Optical rotation of unpolarized light. Alexander Langsdorf, Jr., and Lee A. DuBridge; *J. O. S. A.* **24**, 1–3, Jan., 1934. "The question as to what happens to a beam of unpolarized light in passing through an optically active medium does not seem to have been given a definite answer. If such a beam can be regarded as made up of a large number of elementary components, each plane polarized, then each component should suffer a rotation. Consequently, if an unpolarized beam is separated into two parts and one passed through a dextro- and the other through a laevo-rotary solution, such that the sum of the rotations is 90°, the emergent beams should be incapable of interference. With the use of a Fresnel bi-prism it was found that the interference fringes disappeared when the optically active solutions were in place. They reappeared when the field of view was examined with a quarter-wave plate, showing the existence of circularly polarized light as expected." The experiment described in this paper is suitable for the advanced student laboratory.

Collecting spilled mercury. C. V. Boys; *Nature* **134**, 29, July 7, 1934. To pick up mercury from a floor or lecture table having a smooth cork carpet covering, lightly sprinkle the area with drops of water from a wash bottle, sweep the wetted globules of mercury together with a squeegee or the straight edge of a piece of strawboard, and then with the same tool or a smaller one sweep them into a small dust-pan made of thin celluloid or even cardboard.

The production of liquid oxygen as a lecture table demonstration. Chas. T. Knipp; *Proc. Ind. Acad. Sci.* **43**, 192, 1934. A 1-l round bottom flask is provided with a stem about 3 cm in diameter and 20 cm long, to the end of which is sealed a small Dewar vessel of capacity about 4 ml. The apparatus is evacuated, filled to a pressure of 2.5A with tank oxygen and sealed off. When the stem and Dewar vessel are submerged in liquid air, the oxygen condenses in the stem and trickles down into the Dewar vessel. If after 1 min. the apparatus is removed from the liquid air, it will be found that 2–3 ml of liquid oxygen will have collected, enough to last a half hour or more. Frost which collects on the Dewar vessel may be removed by dipping it in water. From a knowledge of the volume, pressures and densities involved, it is a simple matter to calculate the volume of liquid oxygen that the apparatus should yield when cooled.

A new lecture table demonstration to show that cathode rays leave the cathode normally. Chas. T. Knipp; *Proc. Ind. Acad. Sci.* **43**, 192–193, 1934. An ordinary discharge tube is equipped with a cathode consisting of an aluminum cylinder about 2 cm in diameter and 4 cm long. Around this at equal intervals are placed single turns of, say, No. 20 nickel wire. The tube is then evacuated, primed with helium to make the cathode rays more visible, and sealed off at a pressure giving a Crookes dark space of about 2 cm and cathode rays extending to the walls of the tube. When a discharge is passed through the tube, the rays fill the space out from the cylindrical cathode over its entire length, *except* where the single turns of wire are located. Although each wire is a conductor, it casts a shadow because the cathode rays leave its surface normally.

Mariotte's bottle. E. L. McCarthey; *Science* **80**, 100, July 27, 1934. A stoppered reservoir is supplied with an air

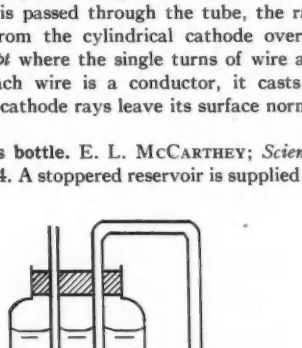

Fig. 1

inlet and a siphon (Fig. 1). "When the siphon is working, the pressure at the bottom of the air inlet tube is obviously just atmospheric, for if it were greater air would not enter; it cannot be less because it is in contact with the atmosphere. If the entrance to the siphon is at this same depth, then it will always be supplied with liquid at atmospheric pressure and will deliver a flow under the constant head h, regardless of the changing depth within the reservoir." D. K. B.

Lantern slides on "frosted" gelatine. C. E. POWER; *Science* **80**, 189–190, Aug. 24, 1934. Cellophane has been suggested as a vehicle for making lantern slides but it has the disadvantages that with aluminum-surfaced screens there is an undesirable glare even when yellow cellophane is used and, unless great care is taken, it does not take ink uniformly. As a substitute for cellophane, *thin*, translucent, onion-skin paper is excellent. Still better is the "frosted" gelatine sheet for flood lights by Klieg; lines drawn on this sheet with ink appear in smooth transparent color on a gray background when projected, and lines drawn with plain water appear as perfectly white lines. Details may be worked in with pencil. D. K. B.

A simple pump for inflating balloons. RICHARD M. SUTTON; *Science* **80**, 250, Sept. 14, 1934. Attach the gas inlet to G (Fig. 1), open valve A, and let gas into C; then

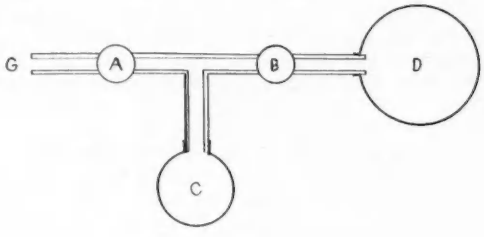

FIG. 1

close A, open B and force the gas into the balloon D by manual pressure. Repeat the cycle as often as necessary to secure complete inflation. D. K. B.

GENERAL PHYSICS AND RELATED FIELDS

Recent developments in architectural acoustics. PAUL E. SABINE; *J. Frank. Inst.* **217**, 443–458, Apr., 1934. Nineteen years ago Professor Wallace Sabine, of Harvard, the founder of architectural acoustics, gave an address on the subject before the Franklin Institute. Since that time great improvements have taken place in both the production and the measurements of the intensity of sound of all audible frequencies, mainly due to the vacuum tube and amplifier. It is now known that the response of the ear to differences of sound intensities is roughly logarithmic; on the average any given intensity must be increased by about 26 percent of itself before the ear will record a difference in loudness. The study of sound insulation has established that materials like felt reduce the sound transmitted through them to a much smaller extent than solid walls, 4 in. of felt giving less reduction than 1 in. of solid plaster. The transmission through walls depends on their forced vibrations, and the sound reduction produced by them is nearly proportional to the cube of the weight per square foot of wall. A combination of a heavy and a light construction elastically coupled is the most effective means of securing high insulation without excessive weight or thickness. Sound insulation is a problem of structure rather than of materials.

Metric system in China and Turkey. ANON.; *Nature* **133**, 59, Jan. 13, 1934. This year China adopted the metric system of weights and measures in the Customs service and in the collection of the salt tax, and Turkey has made it obligatory throughout her dominions. In Great Britain the most that has been achieved so far is the legalization of the use of the system; apparently its fuller use, "like the introduction of the 24-hour clock, is unduly delayed by the prevalent inertia of unscientific public opinion."

INTERMEDIATE AND ADVANCED PHYSICS

Fundamental concepts in the theory of probability. T. C. FRY; *Am. Math. Mo.* **41**, 206–217, Apr., 1934. The leading definitions of mathematical probability are discussed with a view to pointing out their relative advantages and disadvantages, not only from the logical standpoint, but also as regards their degree of resemblance to the concept of probability as it is used in ordinary life to refer to the degree of uncertainty one may feel about an event. It is pointed out first that (1) the mathematical definitions refer to the *number* which measures probability and not to probability itself, (2) none of these definitions can be applied to every important situation with which the theory deals, (3) all of them assume some knowledge in advance as to what we mean by "equally likely," and (4) this phrase cannot be defined because "likely" refers to the undefinable concept of probability, not to the mathematical number. The three most important definitions are then discussed; namely, Laplace's definition, the series definition, and the population. The author concludes "that we are better off with many definitions than with only one; because our world of scientific experience is so broad and complex that a single definition can seldom be good enough to satisfy all our practical needs." "There is a connection between our mathematical thought and the world about us—a connection which we cannot shake off by the mere denial of any interest in it, because the very foundations and language of our science have their being in the world of sense, however ethereal the superstructure we may rear upon them." "The rejection of any definition because it postulates a concept of equal likelihood is merely a refusal to recognize the true source of our thought processes, which in the last analysis spring, not from a dictionary which defines words by means of words, but from the common experience to which in some mysterious fashion we are all common heirs."

Displacement of a rigid body. C. J. COE; *Am. Math. Mo.* **41**, 242–253, Apr., 1934. "Most modern texts on mechanics express in vector form the basic theorems and formulas on the continuous motion of a rigid body, . . . and as so expressed they possess a very striking clearness and simplicity. But a similar treatment of the finite displacements is lacking, the reason being doubtless that the discussions to be found in the literature are in coordinate form or involve concepts much more complex than that of the simple vector." The present paper presents a new vector treatment of finite displacements, and its extension to the case of continuous motion, that presupposes only an understanding of the elements of vector algebra. Among the theorems proved are: Rodrigues' formula, Euler's theorem on the displacements of a rigid body with one point fixed, composition of rotations, Chasles' theorem, and composition of twists.

Maximum optical paths. T. SMITH; *Nature* **133**, 830–831, June 2, 1934. In a recent article on quantum mechanics [K. Darrow, Rev. Mod. Phys. **6**, 23 (1934)] an old mistake in the literature is repeated in the statement "that optical paths are routes sometimes of maximum and sometimes of minimum time, and that for this reason it is appropriate to refer to them simply as stationary paths." The foundation is wrong though the conclusion is right. "The facts are that the time happens to be a minimum when the path does not include an image of an end point of the range considered, but that if the path contains such an image the time is neither a maximum nor a minimum—it is simply stationary. Thus in Fig. 1, if A', the image of A, is an internal point of

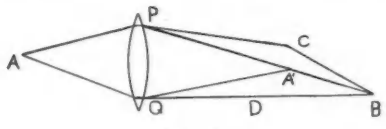

FIG. 1.

the path interval APB, so that the optical lengths APA' and AQA' are equal, the path $APCB$ is obviously longer and the path $AQDB$ obviously shorter than the stationary path $APA'B$. It is clearly a trivial matter to demonstrate that no given optical path is ever a maximum. The error perhaps arose from a mistaken attempt to illustrate the alternate occurrence of maxima and minima by the various optical paths between the two foci of an elliptical mirror; and its currency is doubtless due to the fact that the coincidence in space of the object and image fields for reflection makes confusion of thought particularly easy. . . . In refraction, the distinction between the object and the image spaces is usually forced on a student's attention by the experimental conditions. In reflection the importance of maintaining a similar distinction has to be forced on a pupil's mind by his instructor."

Gyromagnetic measurements and their significance. L. F. BATES; *Nature* **134**, 50–51, July 14, 1934. A number of periodical and textbook treatments of gyromagnetic measurements, perhaps unintentionally, show three main tendencies: (1) they obscure the fact that credit is due to O. W. Richardson, who was the first to show that, if the electron is responsible for ferromagnetism, then it ought to be possible to make quantitative measurements in gyromagnetism; thus, the production of angular momentum by change in magnetization is known as the Einstein-de Haas effect, although it was predicted by Richardson in 1908 and not even experimentally detected by Einstein and de Haas until 1915; (2) they disregard much of the earlier work on the subject, view certain results as merely approximate and neglect much of the latest work; (3) they suggest that important sources of error were entirely overlooked by some workers. The author outlines some of the history of gyromagnetic investigations in support of his assertions. In conclusion, he finds "no valid reason why theoretical physicists should consider the gyromagnetic ratio for simple ferromagnetic substances, and for simple paromagnetic substances, to be other than m/e and $(1/g)2(m/e)$, respectively, in the present state of our knowledge."

The work of the Bureau of Standards in electricity and radio. E. C. CRITTENDEN; *Sci. Mo.* **37**, 405–416, Nov., 1933. The general problem of providing a highly accurate system of standard electrical units is set forth, and the work leading to the system put into use in 1912 is described briefly. Some of the methods now being used to establish a better system (which will perhaps be put into use in 1937) are described in more detail. Many of the other activities of the Bureau along electrical and magnetic lines are outlined, and the article is copiously illustrated with photographs and drawings of apparatus. The author is chief of the Electrical Division of the Bureau of Standards.

G. A. V.

Discovery and early history of the positive electron. KARL K. DARROW; *Sci. Mo.* **38**, 5–14, Jan., 1934. The first positive-electron track to be identified as such occurred in Anderson's cloud chamber at Pasadena, in August, 1932, and was apparently of cosmic-ray origin. A little later, Blackett and Occhialini, in Cambridge, detected a number of them in their expansion chamber; these had originated in a cosmic-ray shower. Together with Chadwick, these workers then produced positive electrons artificially by bombarding lead with the radiations from beryllium which was itself being bombarded by the α-particles from polonium. Curie and Joliot were able to show that it was the photons from the beryllium, rather than the neutrons, which were mainly responsible for the emission of positive electrons from the lead. It was found that when lead is the bombarded metal, the yield increases with increasing photon energy and that when different metals are bombarded by the polonium-beryllium photons, the yield increases with increasing nuclear mass. Curie and Joliot also have observed that positive electrons are emitted by aluminum, boron and beryllium (but not by lithium) when bombarded by polonium α-particles, and have constructed a source giving 30,000 of them per second. According to the quantum-mechanical theory of Oppenheimer and Plesset, a pair of electrons, one positive and one negative, is sometimes created out of a photon of

sufficiently high energy when it is in the neighborhood of an atomic nucleus; the agreement between the predictions of this theory and the rather large number of facts which have recently become known is most gratifying. The article is illustrated with some of the photographs which formed the first-hand evidence of the existence of the positive electron. G. A. V.

Physics Teaching and Science Education

A plea for instruction in photography in high schools. Tyler Gaskill Price; *Am. Phot.* **28**, 400–406, July, 1934. Most snapshots made by amateurs are technically poor because the operators lack training in photography. In high school, courses are given in handwriting, shorthand writing, free-hand and mechanical drawing, and printing; but the most popular and actually the most powerful single tool of the graphic arts which can be yielded by a single individual—the camera—is neglected. The student is taught the principles of lenses, prisms, and mirrors and their application to the telescope, microscope and spectroscope—instruments with which not one in a million students will ever come into direct contact—but the camera is left practically unmentioned. A little study of the principles and practice of photography would "minimize the number of disappointing failures and would better the quality of all the millions of little prints in the American family album." D. K. B.

Some curriculum developments in Los Angeles. W. B. Featherstone; *Clearing House* **9**, 10–13, Sept., 1934. In the Los Angeles city schools, the program at the senior-high-school level is being modified to provide "for courses of rather generalized and less technical character to meet the generalized and social needs of pupils who do not have either the ability or the interest to pursue the parallel courses of rather specialized and more highly technical character in the conventional fields." A three-year junior-high-school basic course in general science is being developed, which will avoid "what seems to be a real weakness in most general science textbooks; namely that they are sketchy, sporadic, or overcrammed with unrelated details and too technical in treatment." This is to be followed by a senior-high-school course in general physical science which will be more general in character of content and less technical in treatment than the usual course in physics and chemistry.

Science in secondary schools and colleges. Herbert W. Rogers; *Sch. and Soc.* **40**, 334–336, Sept. 8, 1934. At Lafayette College a study was made of the grades of students in elementary physics, chemistry and biology. Some of the conclusions are: grades in chemistry and physics are more closely related to general academic standing (av. $r=0.75$) than to intelligence (av. $r=0.47$); students who have had physics or chemistry in high school achieve a higher grade in the corresponding science in college than do those who take the science for the first time in college; there is a considerable discrepancy between college grades in the three sciences, which may not be accounted for by differences in intelligence nor in general academic accomplishment.

Looking ahead in science teaching. Charles H. Lake; *Sch. Sci. and Math.* **34**, 136–143, Feb., 1934. The author is superintendent of the Cleveland, Ohio, public schools. The following excerpts from his paper are of particular interest. "There is a story, more or less mythical I suppose, to the effect that when Henry George went to one of our great American colleges to explain his economic theories to the economists there, he came away disheartened and said that the only men there who could understand his plan were the scientists. Whether their training gives the scientists any particular advantage in understanding principles in other fields of learning or not, they certainly have an obligation to apply the techniques they have acquired for the solution of problems in science to problems in the social field, just as they have an obligation to interpret their research in science to society so that the full significance of their discoveries may be realized by their unscientific neighbors." "In our schools we must have much science. Personally, I advocate it in all grades from the third through the twelfth. In grades 7 to 12, there should be some reorganization. We have compartmentalized it too thoroughly, and we have been too radical in our demands for rigid course units. In grades 7, 8 and 9 the course should be organized so that each pupil will have 3 periods a week; in grades 10, 11 and 12 the science courses probably will have to be elective. These courses should all be 5 periods a week. . . . This means, in most cases, simply a reorganization of the laboratory work. . . . There has been some research on this subject and for all pupils with intelligences of 90 or above the results show that the pupils who have 5 periods a week do just about as well as those who have 6 periods. I have supervised classes in physics that spent 10 periods a week, 8 periods a week, 7, 6, and 5; and while I realize that it is nice to have plenty of time, it seems to me that the position of the science teacher will be strengthened if the work is reorganized on a 5-period basis."

Research studies relating to the teaching of science. C. J. Pieper; *Sci. Educ.* **18**, 112–116, Apr. 1934. A bibliography for the year 1933. The studies are classified under 13 different headings.

The work of science is to substitute facts for appearances, and demonstrations for impressions.—John Ruskin.

Nothing has tended more to retard the advancement of science than the disposition in vulgar minds to vilify what they cannot comprehend.—Samuel Johnson.

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